Assessment of the benefits of Fire Extinguishers as fire safety precautions in New Zealand Buildings

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Abstract

There were over 25,488 fire incidents recorded in New Zealand in 2007/08, according to the New Zealand Fire Service (NZFS) 2006/07 Annual Report. These fires resulted in 34 fatalities and many more serious injuries and accounted for thousands of callouts attended by the NZFS. The NZFS also recorded 8734 incidents of use of fire extinguishers and hose reels/garden hoses where fire incidents were contained by occupants / passer bys.

Current New Zealand regulations are not definitive of requirements therefore the provision of fire extinguishers and hose reels is debated. Current legislation provides guidance to specific conditions for the installation of fire extinguishers and hose reels.

A survey done in UK and some European countries in 2000 by EUROFEU identified that in 80% of the cases a portable fire extinguisher successfully extinguished the fire and in 75% of those cases the Fire Service was not required to attend. These incidents were therefore not recorded in any official statistics. According to the survey it was estimated that fire extinguisher usage actually could save £1.5 million each year in terms of Fire Service resources.

This report uses historical data available from 1990 – 2007 from the NZFS FIRS database and usage statistics generated from conducting a survey of service agencies for fire extinguishers in New Zealand. This report also evaluates prescriptive requirements existing in New Zealand and compares with prescriptive requirements outside of New Zealand.

The current statistics using the NZFS-FIRS data shows that there is a downward trend in the use of extinguishers; however these statistics may not reflect the true usage patterns of extinguishers. Data collected from a survey of

service agencies shows that the majority of extinguisher usage does not get reported for official statistics. State reason

The further cost benefit analysis has been done for typical occupancies where the use of extinguishers is expected because of the occupancy and competence level of occupants. Risk simulations for different scenarios of fire protection system use and success was used to determine cost of a fire in terms of direct property losses, Fire Service costs and other indirect economic losses. Direct property losses have a direct consequence to the building owner while other costs reflect more to the New Zealand economy and Fire Service and may have an indirect bearing to the building owner.

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1 INTRODUCTION

1.1 Initiative for Research

The current New Zealand regulations require the installation of portable fire extinguishers and hose reels under specific circumstances in buildings as a Fire Safety Precaution. These documents are the Compliance Document C/AS1[1] issued by the Department of Building and Housing, New Zealand Sprinkler Standards[2], Health and safety in Employment Act, Hazardous substances and New Organisms Act, New Zealand Fire Service Code of Practice, Maritime Safety Act[3,4].

These current New Zealand regulations are not definitive of the requirements as each legislation provides guidance to specific conditions that require installation of portable fire extinguishers and hose reels. Some legislation overrides others to have the installations removed under specific circumstances. This is causing a lot of confusion amongst designers, regulators, inspectors, Fire Service, the fire equipment industry and the building owner / operator. The objective of this research project is to assess potential cost benefits of having the portable fire fighting equipment installed in New Zealand buildings in terms of life safety and property protection.

A well maintained active system and passive systems provide a building with a high degree of fire safety both in terms of life safety and property protection at all times. Fire extinguishers can provide additional protection while the building is occupied and they can significantly reduce losses resulting from a fire incident if used successfully to extinguish a fire in its initial stages. The ssuccessful use of an extinguisher is dependant on the availability of a correct appliance, the training of user and maintenance of the appliance.

The objective of this research is to determine benefits of installing extinguishers in a building. This research uses an information gathering exercise involving literature search for fire extinguisher benefit studies around the world, assimilation of current information available from Fire Service and service companies regarding usage of extinguishers on fires, calculating a standard cost for installation and maintenance of extinguishers for the life-time of a building. (This includes required training costs), discussions with fire professionals in terms of risk assessment to life safety by removing extinguishers from buildings, a risk analysis to determine fire losses and compare it with fire scenarios for different building types and a survey of fire extinguisher usage in New Zealand using feedback from the extinguisher service companies.

1.2 Hand Operated Fire Fighting Equipment (HOFFE)

Hand operated fire fighting equipment (HOFFE) are considered to be the first aid devices for fighting a fire which is small and could develop into a large fire endangering life safety and property if not controlled. HOFFE installed in buildings and mobile plant, are classified as fire extinguishers, hose reels, fire blankets etc. Installation, selection and maintenance of HOFFE are regulated by relevant standards in New Zealand.

This research evaluates the cost benefits of installing extinguishers, therefore all data analysis and risk analysis in further sections deal mainly with information relating to extinguishers.

1.2.1 Legislation

The applicable industry standards relating to Fire Extinguishers in New Zealand are as follows:

AS/NZS (combined Australian and New Zealand Standard)

1841: 2007 Portable fire extinguishers

1841.1 2007: General Requirements

1841.2 2007: Specific requirements for water type extinguishers

1841.3 2007: Specific requirements for wet chemical type extinguishers

1841.4 2007: Specific requirements for foam type extinguishers

1841.5 2007: Specific requirements for powder type extinguishers

1841.6 2007: Specific requirements for carbon dioxide type extinguishers

1841.1 2007: Specific requirements for vaporizing-liquid type extinguishers

1841.1 2007: Specific requirements for non-rechargeable type extinguishers

1850: 1997 Portable fire extinguishers – Classification, rating and performance testing.

NZS (New Zealand Standard)

4503: 2005 The distribution, installation and maintenance of hand operated fire fighting equipment for use in buildings

It is important to note that NZS 4503 is currently under review, and is likely to be dropped in favour of adopting the following Australian standards:

AS (Australian Standard)

1851: 2005 Maintenance of fire protection equipment

1851.1: 2005 Portable fire extinguishers and fire blankets

2444: 2001 Portable fire extinguishers and fire blankets – Selection and location.

1.2.2 Classes of Fire

In order to select the most suitable type of extinguisher for a particular situation, the various types of fires likely to be encountered have been classified according to fuel type. The following data has been extracted from the New Zealand Fire Service[5,6] and Wormald training documents[7].

Class A Fires involving carbonaceous solids (e.g. wood, cloth, paper, rubber and many plastics. Basic cover is required to provide protection against Class A fires. Suitable extinguishers for this type of risk would include:

Water Type, Dry Powder displaying an A rating, Foam displaying an A rating

Class B Fires involving flammable and combustible liquids (e.g. Petrol, diesel and methylated spirits. Protection from flammable liquid fires shall be provided by the following types of extinguishers:

Foam, **Dry Powder,** ***Carbon Dioxide (limited effectiveness and possible splash hazard)***

Note that water must **not** be used on Class B fires. Note also that alcohol-resistant foams should be used for risks involving polar solvents. Polar solvents are liquids that will mix to any degree with water. Examples of this type of fuel are alcohols, enamel and lacquer thinners, methyl ethyl ketone (MEK), and acetone.

Class C Fires involving combustible gases (e.g. LPG, CNG and propane)
It is recommended that isolation at the source as the only safe way of extinguishing a flammable gas fire. It is recommended that extinguishing the fire by any other means if isolation is possible **immediately** after extinguishment. Suitable extinguishers for Class C fires are:

Dry powder, Carbon Dioxide (limited effectiveness)

If extinguishment is not undertaken immediately, control any potential fire spread with an extinguisher appropriate to the risk, and use water to cool any pressurized cylinder experiencing flame impingement or high levels of radiated heat.

Class D Fires involving combustible metals (e.g. Magnesium, aluminium and sodium. This type of fire may be more common than first suspected, for example in a car parts warehouse that stocks magnesium alloy wheels. Specialist advice on extinguisher selection should be sought.

Class E Fires involving electrically energized equipment

While electricity is not a fuel as such, its impact on extinguisher selection requires that it be given its own class. Where an extinguisher is likely to be used on a fire that involves electrically energized equipment, it is vital that the extinguishing medium be non conducting. Extinguisher types that comply with the AS/NZS 1850 test for electrical non-conductivity are:

Dry powder displaying an E rating, Carbon Dioxide

Note that water is a conductor of electricity, so water and water based extinguishers including foam and wet chemical must **not** be used on fires involving electrically energized equipment.

Class F Fires involving cooking fats and oils (eg. Shallow and deep fat fryers. Protection from cooking oil and fat fires can be provided by the following types of extinguishers:

Wet Chemical, Foam (limited effectiveness), Dry powder (BE type only and limited effectiveness), Carbon Dioxide (limited effectiveness and splash hazard)

Note that only wet chemical extinguishers are truly effective on Class F fires. Fire blankets are also deemed to be effective in most situations involving Class

F risks, however it is recommended to use fire blankets in conjunction with an appropriate extinguisher.

1.2.3 Classifications and Ratings of extinguishers

Classification is a way of determining by test, which class or classes of fire a particular extinguisher is suitable for use on. Rating is a method of measuring the comparative performance of different fire extinguishers on a given class of fire, under specific test conditions. The method of classifying and rating fire extinguishers used in this country is contained in AS/NZS 1850.

The classification of an extinguisher is based on its ability to extinguish a fire comprised of purely Class A, B, C, D or F fuel. If a particular extinguisher meets the test requirements for a Class A fire, it will display the letter 'A', if it meets the requirements for a Class B fire, it will display the letter 'B', and so forth. Many extinguishers will have more than one classification, i.e. they are capable of extinguishing more than one class of fire, which is important because in practice fires often involve fuel from more than one class. This also means that one type of extinguisher can be selected to cover a variety of risks.

A numerical rating is provided as an indicator of the performance capability of an extinguisher for Class A and B fires, as determined by the test. This number precedes the classification for that extinguisher, i.e. 2A. The rating values range from 1 to 10 for Class A, and 2 to 80 for Class B.

In general, an extinguisher with a rating of 2A will be able to extinguish a Class A fire that is twice as large as an extinguisher with a 1A rating, and so on. When an extinguisher is classified and rated for more than one class of fire, the classifications and ratings will appear in alphabetical order, separated by a colon, i.e. 2A:40B.

1.2.4 Electrical Non-conductivity Rating of extinguishers

While electricity itself is not a fuel as such, it is considered such an important hazard that it is given its own classification. A fire extinguisher that is classified for use on fires involving electrical hazards will display the letter 'E'.

This classification will usually appear behind the other alphanumeric ratings on an extinguisher, i.e. 2A:40B:E, and indicates that the extinguishant, as discharged, is non-conductive. Remember that an extinguisher appropriate for the class(es) of fire involved must still be selected. Most electrically energised fires are usually Class A fires, so an extinguisher with both an 'A' and 'E' classification would therefore be required. Extinguishers produced prior to 1981 were marked 'C' to indicate electrical non-conductivity.

1.2.5 Determining Required Level of Protection

When determining the required level of extinguisher protection in a particular building, a number of assessments need to be made. These considerations can be broadly categorised in the following manner:

Selection: What type of extinguisher is most suitable for a building, part of a building, or specific risk within a building.

Distribution: The number and size of extinguishers required based on the type of risk that needs protecting.

Installation: How extinguishers should be positioned within a building, including mounting and signage requirements.

1.2.6 Selection of Extinguisher Type

There are a number of different types of extinguishing mediums available today, and they all have different performance characteristics that depend largely on the type of fire they are attempting to extinguish. Extinguishers are selected based on the extinguishing agent it uses. Some additional factors affecting the selection of extinguishers are as below.

(a) Size and mass of the fire extinguisher and the ability of the user to carry and operate it;

(b) Possible effects of adverse environmental conditions on the fire extinguisher and it support fixture;

(c) Possibility of adverse reactions, contamination or other effects of an extinguishant on manufacturing processes or equipment;

(d) Possibility of winds or draughts affecting the distribution of the extinguishant;

(e) Possible effects of vibration at the installation location on the extinguisher components or contents e.g. compaction of dry powder extinguishant;

(f) Possible effects on health and safety when extinguishers are used in confined spaces, e.g. CO_2 may cause oxygen deficiency, BCF may produce hazardous decomposition products and dry powder may temporarily reduce visibility or cause respiratory irritation.

Table 1.1 below summarizes the selection criteria based on the extinguishing agent and its suitability.

AGENT	Class A Wood Paper Plastics	Class B Flammable Liquids	Class C Flammable Gases	Class E Electrically Energized Equipment	Class F Cooking Oils and Fats	Class D For fire involving combustible metals use special purpose extinguisher
Water	**YES**	NO	NO	NO	NO	Dangerous if used on flammable liquid, energized electrical equipment and cooking oil/fat fires
Wet Chemical	YES	NO	NO	NO	**YES**	Dangerous if used on energized electrical equipment
Foam	YES	**YES**	NO	NO	LIMITED	Dangerous if used on energized electrical equipment
ABE Powder	**YES**	**YES**	**YES**	YES	NO	Look carefully at the extinguisher to determine if it is a BE or ABE unit as the capability is different
BE Powder	NO	**YES**	YES	YES	LIMITED	
Carbon Dioxide	LIMITED	LIMITED	LIMITED	**YES**	LIMITED	Not suitable for outdoor use
LIMITED indicates that the extinguishant is not the agent of choice, but may have a limited extinguishing capability Solvents such as alcohol and acetone mix with water and therefore require alcohol-resistant foam **Bold** text indicates the class or classes in which the agent is most effective						

Table 1.1: Extinguisher Selection Chart

1.2.7 Distribution of Extinguishers

Hand operated fire fighting equipment (HOFFE) is distributed and located as required by NZS 4503:2005[8] or by any stricter requirement of a manufacturer or regulatory authority. Distribution of fire extinguishers shall be in accordance with the hazard present in the area to be protected and the size of the area.

The classification and rating of each fire extinguisher shall be at least equal to that which is appropriate to the hazard of the area protected. Using a number of lower rating extinguishers is not permitted to attain the level of protection. It is permitted to have extinguishers of higher classification and rating than that required for the area being protected. Extinguishers having more than one classification and rating are regarded as acceptable in terms of each classification and rating if the hazards are in the same protection area.

Where hose reels are not present, or fail to meet any of the requirements under NZS 4503:2005[8], basic cover shall be provided by fire extinguishers as per table 1.2.

Fire hazard Classification	Maximum Floor Area (m^2)	Minimum Extinguisher Rating	Minimum Number of Extinguishers per Level	Max Distance of Travel to an Extinguisher (m)
Light	300	2A	2	30
Medium	200	2A	2	30
High	150	2A	2	30
In the case of intermediate levels, such as mezzanine floors, extinguishers shall be placed so that at least **two** are readily available to service such areas of which at least **one** shall be on the intermediate level.				

Table 1.2: Extinguisher cover to floor area

Where specific risks other than Class A are present, extinguishers of a type appropriate to the risk shall be provided. The Fire Service recommends positioning these extinguishers not more than 15 m from the risk they are protecting, but not so close that they cannot be reached due to proximity to the fire. If a premise uses dangerous goods or performs spray coating, additional cover complying with the Dangerous Goods Regulations and the Spray Coating Regulations may be required.

1.2.8 Installation of Extinguishers

The installation of fire extinguishers within a premise shall comply with the requirements of NZS 4503:2005[8] and the manufacturer's instructions, to ensure the equipment will be secure and operate as intended.

1.2.9 Maintenance of Extinguishers

Inspection, testing and maintenance of fire extinguishers are set out in part 6 of NZS 4503:2005[8] to comply with AS/NZS 1841. All equipment shall be maintained in a fully charged and operational condition and kept in its designated place at all times ready for use in the event of a fire. Recommended maintenance procedures are also advised by the Fire Service.

1.2.10 Fire Extinguisher Use and Training

To optimize effective use of fire extinguishers, personnel should be trained in the use of fire extinguishers. Training of personnel in the use of fire extinguishers is desirable as it helps in controlling a fire in its initial stages and more so in occupancies requiring high degree of life safety such as hospitals, homes for persons with disabilities and welfare centres. It is required by an employer to provide such training to meet their obligations under the Health and Safety in Employment Act. For details on recommended training procedures refer Appendix C.

1.3 Historic Data and Case Studies

1.3.1 Domestic First Aid Fire Fighting Assessment (UK – 1992)

A Home Office Research Programme[9] carried out by the Fire Research and Development Group carried out an assessment of the level and extent of current domestic first aid fire fighting. This project was undertaken in two parts: the first stage involved an information gathering exercise involving literature search, discussions with fire professionals and two surveys of the general public.

The conclusions of this research included a high concern for a fire in a home amongst general public despite low incidence, majority of fires were discovered within a minute of starting and the average time to tackle a fire was 2.5 minutes. The research indicates that both discovery and fighting a fire is very quick. 73% of the fires in the survey had flames less than 1 foot (300mm) and 81% of the respondents termed the fires as "small and easy to put out". Most fires were extinguished by using a damp cloth or water, except for electrical and fat fires. Most people responded instinctively to fight a fire with item readily available rather than using a specific extinguisher. Most important conclusion was that 90% of home fires were not reported to the Fire Service.

The above research was specific to fires in residences however it does highlight that majority of fires in a home environment could be easily and quickly tackled, with an extinguisher.

1.3.2 Fire Extinguishing Trades Association (FETA) Survey – Europe 2002

A joint survey[10] into the use of portable fire extinguishers in UK was undertaken by the Fire Extinguishing Trades Association (FETA) and the Independent Fire Engineering and Distributors Association (IFEDA) in 2002. This survey was carried out in 2002 over a 4 month period, with data collected from service engineers of FETA and IFEDA member companies.

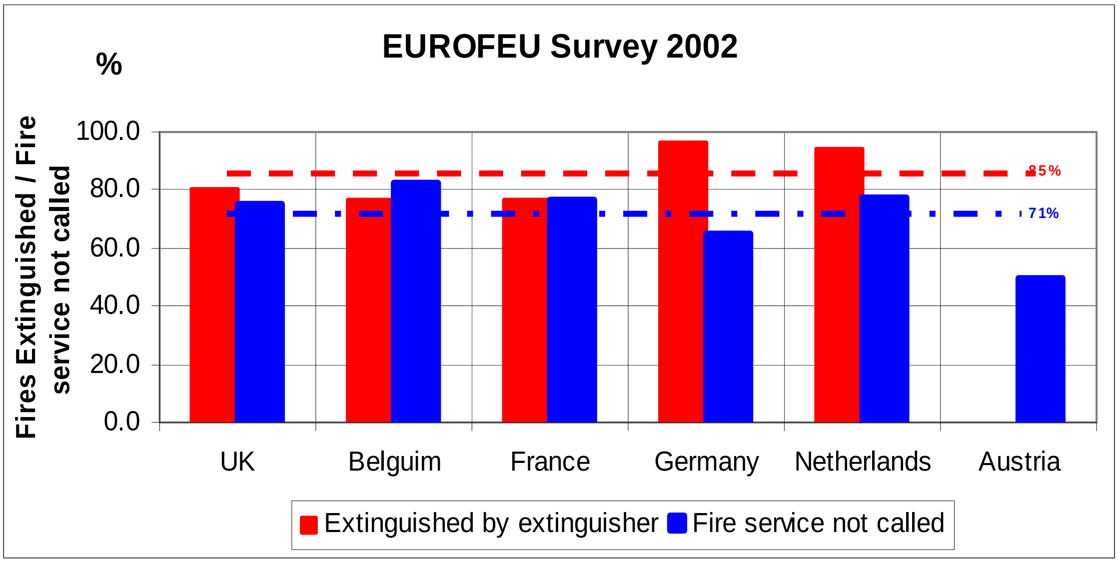
The survey comprised of 2173 incidents (recorded by FETA and IFEDA) and concluded that 80% of the cases (1737 incidents) portable fire extinguishers successfully extinguished the fires, 75% of the cases (1637 incidents) the Fire Service was not required to attend and an estimated £ 5.1 million each year was savings projected in terms of fire service resources.

In addition to the UK findings, a wider European survey was conducted over a three month period in 2002 by the European Committee of the manufacturers of fire protection equipment and fire-fighting vehicles (EUROFEU). This was carried out in six EUROFEU countries; Austria, Belgium, France, Germany and the Netherlands.

The outcome of the European survey was very similar to the UK survey comprised of 2627 incidents (recorded across the six countries during the survey) and concluded that 81.5% of the cases (2163 incidents) portable fire extinguishers successfully extinguished the fires and 74.6% of the cases (1961 incidents) the Fire Service was not required to attend. The table below summarises the survey in UK and European countries.

	UK	Belgium	France	Germany	Netherlands	Austria
Total incidents reported	2173	937	696	806	140	48
Extinguished by extinguisher	1737	718	534	779	132	0
Not extinguished by extinguisher	436	219	162	27	8	0
Fire Service called	523	138	165	168	32	24
Fire Service not called	1637	772	531	526	108	24
Not known	13	27	0	112	0	0

Table 1.3: European Survey results



Austria did not record data on fires extinguished

Figure 1.1: EUROFEU Survey results showing extinguisher effectiveness

1.3.3 Fire Extinguisher usage recorded by the Swedish Fire Service- 2006

The Swedish Rescue Services Agency commissioned a cost-benefit analysis of fire extinguishers in residences[11]. This was carried out in the early nineties by Birgitta Juås and Bengt Mattsson at Karlstad University. There were no Swedish Fire Service statistics to estimate benefits and the study was based on Norwegian Fire Service Statistics. The material was too small to be able to prove any effect in reduced injuries or deaths. However individual insurance payments are linked to the fire brigade turnouts and it was possible to prove that for single occupancy homes the reduction of economic losses was greater than the cost of fire extinguishers. The costs and benefits were more or less equal for apartments.

Following the above study, the Swedish Fire Services has started recording usage of fire extinguishers and hose reels/other hoses in building fires.

However there are no records of individual insurance payments for each fire therefore a straight forward cost benefit analysis was not carried out.

Total Incidents recorded	10495
Fire Extinguishers Used	1752
Fire contained	1066
Fire not contained	535
Not known	151
Percent usage of extinguishers	17
Percent effective in containing fire	61
Percent not effective in containing fire	31
Percent not known	9

Extracted from data sheet provided by the Swedish Fire Service

Table 1.4: Data from Swedish Fire Service

1.3.4 Norwegian Study on cost benefits of fire extinguishing equipment in residences (2000)

The Norwegian regulations for fire preventive measures and fire inspections by the fire brigades were issued in 1990. The requirements for dwellings state that

"All residences shall be equipped with at least one approved smoke detector that can be clearly heard in the bedrooms when the doors are closed"

and that

"All residences shall be equipped with fire extinguishing equipment that can be used in all rooms"

These regulations covered both new and existing homes. The owner is obliged to install the required equipment and the occupant is responsible for the maintenance. In 1997 SINTEF was asked by the Norwegian authorities to evaluate the effect of the regulations regarding fire safety in dwellings. The evaluation studies[12] included cost benefit analysis of the fire preventive measures installed in the dwellings.

Based on the study it was found from the analysis of fire brigade reports that fire hoses and fire extinguishing equipment prevent fire spread by 15% of the domestic fires every year. There was no evidence of the potential material loss due to the fire spreading if the equipment had not functioned / not used. The study therefore assumed that the reduction in insurance company's compensation of fire losses would reduce by 15% per year which was a benefit – to – cost ratio of 2:1.

This was estimated based on the assumptions that one portable extinguisher at 500NOK per housing unit with 10 years of operating time, 2 million housing units and compensation from the insurance companies for material losses in dwelling fires per year is 1500 NOK, the same as 1999 in Norway.

1.3.5 Fire Extinguisher usage data – other parts of the world.

Other than the above recorded studies, there is not a lot of data available to substantiate the use of extinguishers and their effectiveness to contain minor fire incidents.

The National Fire Data Centre[13] collects fire incident data through the United States Fire Administration's (USFA) National Fire Incident Reporting System (NFIRS). The earlier versions of NFIRS included a field called method of extinguishment. Although fire extinguisher was a choice, information was not collected about who (civilian or fire fighter) actually used the extinguisher or about fires in which extinguishers were used but did not put out the fire. This field was dropped in Version 5.0 of NFIRS, which was first implemented in 1999.

In Australia, fire service data available in the public arena is the 'Report on Government Services[14]" which is a publication that reports on emergency management. The data included in this report is only limited to reported fire incidents and level of safe fire practices in the community.

Individual fire service regions provide very limited statistics for method of extinguishment. The New South Wales Fire Brigade reports 21% manual fire fighting aids used for method of extinguishment in its annual statistics report[15] of 2001/02. Manual aids included fire extinguishers. South Australian Metropolitan Fire Services uses the Australian Incident Reporting System (AIRS)[16] for providing statistical information. It does not record method of extinguishment. Metropolitan Fire Board (Melbourne) also provides statistical information in their annual reports[17] but do not include method of extinguishment. Tasmanian Fire Service provides statistics on incident numbers, causes of fire incidents and response times in their annual reports[18]. Other regional fire brigades do not provide any hard statistics on method of extinguishment. Excerpts from various fire service agencies are shown in Figure 1.2 below.

Major method of extinguishment……………………………………………………………………………...104

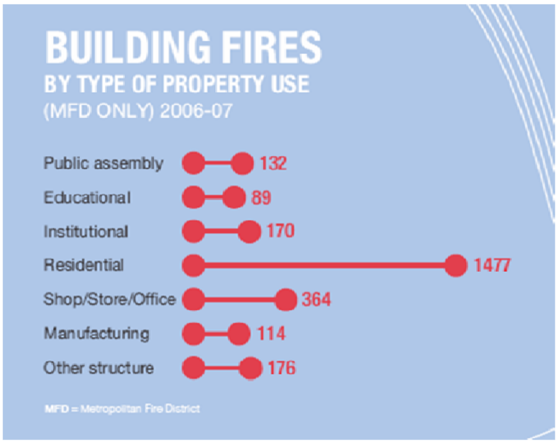
Hose lines with water carried in fire engine tanks accounted for 37% of total major methods of extinguishment. Manual firefighting aids accounted for 21%.

Extracted from the NSW Fire Brigade Annual Statistics Report 2001/02

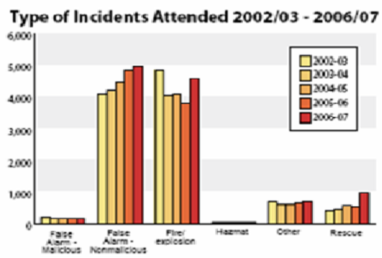
AIRS Table 6a:
Number of Fires Per Property Type

Property Type	1	2	3	4	5	6	7	8	9	TOTAL
Public Assembly	6	8	6	1	0	2	1	0	0	24
Educational	1	8	2	3	1	1	0	0	0	16
Institutional	1	0	1	1	0	1	0	0	0	4
Residential	7	30	56	31	20	35	4	0	0	183
Shop, Store, Office	1	8	5	3	0	1	2	0	0	20
Basic Industry	15	28	5	1	1	2	1	1	0	54
Manufacturing	1	2	4	3	0	3	1	1	0	15
Storage	0	5	9	16	6	2	1	0	0	39
Special	13	81	155	42	6	5	0	0	0	302
Mobile	1	34	140	43	9	2	0	0	0	229
Undetermined	0	0	0	0	0	0	0	0	0	0
TOTAL	46	204	383	144	43	54	10	2	0	886

Extracted from the South Australia Metropolitan Fire Services Annual Report 2006/07



Extracted from the Metropolitan Fire District Fire Statistics 2006/07



Extracted from the Tasmania Fire Services Annual Report 2006/07

Figure 1.2: Extracts form Australian Fire Service Statistical Information

2 Regulatory Requirements in New Zealand

2.1 Fire Safety Precautions in buildings in New Zealand

Fire Safety Precautions (FSP's) is a combination of all methods used in a building to warn people of an emergency, provide for safe evacuation and restrict the spread of fire, provide adequate time to fire service personnel to undertake rescue operations, and includes both active and passive protection. This definition has the same meaning and wording as the definition of "Fire Safety Systems" in the Building Regulations.

Any installation of FSP's in buildings in New Zealand is normally mandated by the requirements of the building code, fire safety clauses C1 to C4 which are regulations made under section 400 of the Building Act 2004. New Zealand Standards that provide the basis for installation and compliance of fire safety systems may also mandate requirements of additional FSP's to be provided. In additional to the above New Zealand Fire Service Code of Practice also may recommend or require the installation of FSP's for safety of the buildings.

Fire Extinguishers and Fire Hose Reels are considered Fire Safety Precautions that are provided within buildings to provide first aid protection and suppress minor fire incidents.

2.2 New Zealand Building Code

The mandatory provisions for building work are contained in the New Zealand Building Code (NZBC), which comprises the First Schedule to the Building Regulations 1992. The relevant NZBC clauses for fire safety in buildings are C1, C2, C3 and C4.

Clause C1 – Outbreak of fire: The objective of this provision is to safeguard people from injury and illness caused by fire. This is achieved by regulating the installation of equipment and appliances that uses solid, liquid or gaseous fuel for combustion to reduce the likelihood of fire

Clause C2 – Means of escape: The objective of this provision is to safeguard people from injury and illness from a fire while escaping and to facilitate fire rescue operations. This is achieved by regulating the means of escape from fire for people to reach a safe place and provide adequate time to fire service personnel to undertake rescue operations.

Clause C3 – Spread of fire: The objective of this provision is to safeguard people from injury and illness from a fire while evacuating a building, provide protection to fire service personnel while carrying out fire fighting operations, protect adjacent units, buildings, other property from effects of fire and safeguard environment from adverse effects of fire. This is achieved by prescribing fire rating requirements, fire and smoke separation requirements, interior and exterior finishes, external fire spread control and active fire safety systems.

Clause C4 – Structural stability during fire: The objective of this provision is to safeguard people from injury, protect adjacent units, other property and allow fire service personnel to carry out fire fighting operations safely by preventing structural collapse during a fire. This is achieved by prescribing the requirements of fire resistance ratings for structural elements of the building.

The Compliance Document C/AS1[1] provides acceptable solutions which is one way but not the only way, of satisfying the NZBC provisions for fire safety in buildings. The methods provided are particularly appropriate for simple, low rise buildings. However alternative solutions developed from specific fire engineering design can be used to satisfy the NZBC provisions and produce more economical results. Part 4 of the acceptable solutions prescribes Fire Safety Precautions based on fire load, occupant load, nature of occupancy and building escape height.

Table 4.1 from the Acceptable Solutions describes the FSP's required in a building. This table lists the fire safety precautions of individual firecells in a building but, on its own, does not provide all the information necessary to satisfy the fire safety precautions of the whole building. Users of the table must be familiar with the definitions and contents of all Parts of the Acceptable Solution. There are significant advantages in exceeding Table 4.1 FSP requirements to achieve other benefits, and specific requirements may apply to less common circumstances not covered by this table.

The acceptable solution only prescribes Fire Hose Reels (FHR's) for sleeping accommodation (SA) and attached and multi-unit residential dwellings (SR) for buildings with specific escape height and occupant load (refer Appendix A). The Acceptable Solution also refers to the substitution of Fire Hose Reels with suitable Portable Fire Extinguishing equipment where use of Fire Hose Reels is inappropriate due to lack of water pressure or because of special hazards (Paragraph 8.2.2, Part 8, C/AS1[1]). The Acceptable Solution also states that the Fire Hose reels are mainly for the use of Fire Service Personnel or people who are trained to use them.

Fire Sprinkler Systems required by the acceptable solution shall comply with the relevant New Zealand Standard amended as shown in paragraphs D2.1 and D3.1 (refer Appendix A).

Paragraph D2.1 amends the sprinkler standard by deleting clause 205 that requires the provision of Fire Hose Reels or Portable Extinguishers.

2.3 New Zealand Standard for Sprinkler Systems (NZS 4541/4515)

The New Zealand Standard for Sprinkler Systems[2] (NZS 4541:2003) clause 205 (Appendix A) requires that hand operated fire fighting equipment (HOFFE) is provided throughout the occupiable area of a sprinkler protected building confirming to either:

a) types an numbers as to comply with NZS 4503[8]; or
b) by a system of hose reels installed to confirm with the building code.

"Appendix D – C/AS1[1]" amended Fire Sprinkler Systems requires that wherever sprinklers are required by the acceptable solution, they shall comply with the relevant New Zealand Standard amended as shown in paragraphs D2.1 and D3.1 (Appendix A).

2.4 New Zealand Fire Service Code of Practice

Section 21(4)(a) of the Fire Service Act 1975[19] requires that the Fire Service issue a code of practice for hand operated firefighting equipment.

Section 21(4)

> " . . . *the Commission may, . . . , make recommendations to the Minister in respect of-*
>
> *(a) The issue of codes of practice or standards prescribing, in relation to proposed or existing buildings,-*
>
> *(iv) The installation and maintenance of hand-operated fire fighting equipment, . . .*"

Any code of practice issued by the Fire Service must be compatible with the fire protection industry standard in order to be effective. The current standard for fire extinguishers in New Zealand is NZS 4503:2005[8] *'The distribution, installation and maintenance of hand operated fire fighting equipment for use in buildings'*.

At present this document is under review, and it is likely to be replaced by the relevant Australian standards to create joint AS/NZ standards, which would be amended as necessary to suit New Zealand's circumstances.

In order to meet obligations under the Fire Service Act and the Fire Safety and Evacuation of Buildings Regulations 1992[20], a code of practice for hand operated fire extinguishers is currently being developed by the New Zealand Fire Service. This code of practice will be based on the relevant Australian standards, in anticipation of these standards being adopted by Standards New Zealand.

Until such time as this code of practice is published, the Fire Service standard will be based on NZS 4503:2005[8]. Therefore until further notice building owners are advised that under Regulation 10 of the Fire Safety and Evacuation of Buildings Regulations 1992, they are to provide fire extinguisher protection in accordance with NZS 4503:2005[8].

The information above, based on NZS 4503:2005[8], is designed to provide guidance to staff in matters relating to hand operated fire extinguishers.

2.5 Fire Safety and Evacuation Regulations

The Fire Service has always placed life safety at the top of its agenda when developing fire safety policy, and rightly so. However with this approach comes an inherent conservatism that is often at odds with what could reasonably be expected of the general populace. One example of this can be found in the Fire Safety and Evacuation of Buildings Regulations 2006[20].

Regulation 13(2)

"The National Commander may require an owner or a tenant of a building to install (at specified locations in the building) and maintain portable fire Extinguishers:

(a) under a code of practice issued under section 21(4)(a)(iv) of the Act; or

(b) if there is no code of practice, as the National Commander determines."

The regulations reflect Fire Services goals by placing emphasis on evacuation as the only response to fire within a building. This approach suits the Fire Service objectives, however it often falls far short of meeting the needs of the building occupier. While the Fire Service seeks to meet its primary objective of saving life, the building occupant has a vested interest in protecting property.

Whether it is a financial incentive, as in the owner of a business who has invested everything into the business; an effort incentive, as in the employee whose hard work is all stored on their computer; or an emotional incentive, as in the family whose home is filled with precious memories and irreplaceable items, the building occupier has any number of reasons for not evacuating at the first sign of fire, and asking him or her to do so is often unreasonable, not be mention unrealistic. Demanding that someone evacuate a building because his or her rubbish bin is on fire, in so doing allowing that small fire to grow into one that may threaten the entire building, may be perceived by the building occupant to be unrealistic, and also lower the worth of the Fire Service in the eyes of the public. Therefore, the Fire Service in its objectives considers the placing of portable fire fighting equipment as a first means of defence for the occupier suitable.

2.6 Construction Act 1959

The first legislation governing the safety of workmen engaged on building and construction work was the Scaffolding Inspection Act 1906. It was a short Act, a little over two pages, requiring notification of intention to erect any structure or framework over 16 ft in height, or any swinging stage, for the support of workmen engaged on building work. It provided for the appointment of inspectors with rights of entry and inspection, and enabled regulations to be made specifying minimum safety requirements. This Act was replaced by the Scaffolding and Excavation Act 1922 which reduced the minimum notifiable height of scaffolding to 12 ft and extended coverage to excavations of a depth of 5 ft or more, and to cranes and lifting gear used in construction work. An inspector was empowered to order unsafe work to cease or to brand and destroy unsafe gear; he could also demand that an employer comply with any requirements of regulations made under the Act.

This Act was amended in 1924 and 1948, and in 1951 was extended to engineering construction. At the same time its provisions were widened in respect of health and welfare. Although the obligation rested on the employer to comply with the requirements of the regulations and with directions made by an inspector, the emphasis rested on inspection. The inspector was commonly regarded as the person mainly responsible for seeing that safe conditions existed in the building and construction industry.

This emphasis was greatly changed in the 20-page Construction Act 1959[21] which replaced the Scaffolding and Excavation Act 1922. The Construction Act 1959[21] was to consolidate certain enactments of the Parliament of New Zealand and to make better provision for the safety and welfare of persons engaged in construction work. This Act was to be administered by the Department of

Labour established under the Labour Department Act 1954, repealed by s. 3 (2) of the Labour Department Amendment Act 1970. This Act applies only to construction work carried out by an employer on the site of the work by way of his trade or business or in the exercise of his functions or for the purpose of any industrial or commercial undertaking.

The construction Act 1959[21] required the employer to provide provisions for the prevention of fire such as fire fighting equipment and materials. This act has been removed and has been substituted by the Health and Safety in Employment Act.

2.7 Hazardous Substances and New Organisms (HSNO) Act

The passing of New Zealand's Hazardous Substances and New Organisms Act (HSNO Act) in June 1996 represented one of the most significant reforms of environmental legislation since the Resource Management Act. The Act came into force in two stages. Provisions relating to new organisms took effect in July 1998. The provisions relating to hazardous substances came into force on 2 July 2001.

A hazardous substance is a defined mixture of elements or compounds either naturally occurring or produced synthetically. Such substances can readily explode, burn, oxidise (accelerate the combustion of other material) or corrode (metals or biological tissue), and/or be toxic to people and ecosystems

A substance is hazardous if it exceeds the threshold for one or more hazardous properties. Most hazardous substances will have more than one hazardous property, for example petrol is flammable, toxic and ecotoxic.

The hazardous properties includes Explosive (Class 1), Flammable (Classes 2, 3, 4), Oxidising (Class 5), Toxic (Class 6), Corrosive (Class 8) and Ecotoxic (Class 9)

Each of the above properties has different levels of hazard – from the least to the most hazardous. The Hazardous Substances and New Organisms Act (HSNO Act) provides controls for all the hazardous properties of a substance. HSNO controls will apply at all stages in the manufacture, use and disposal of hazardous substances. HSNO regulations[22, 23] cover the packaging, disposal, tracking, personnel qualifications, emergency management and identification of hazardous substances and handling.

2.8 Maritime Rules

Maritime Safety Authority of New Zealand prescribes the requirements of safety equipment for fire fighting and fire prevention on board New Zealand Ships. These are prescribed by Maritime Rules which specify numbers and performance requirements.

Part 42B[3] prescribes performance standards for fire appliances, including fixed fire detection and alarm systems, various types of fixed extinguishing systems, fire pumps, portable and non-portable fire extinguishers, breathing apparatus and fire crew suits.

Part 42B[3] complements parts 40A to 40D, which specify the numbers and types of appliances to be carried on various types of ships operating in defined limits.

Part 42B[3], together with part 40 series maritime rules, replaces the regulations entitled the *Shipping (Fire Appliances) Regulations 1989*. These regulations incorporate codes of practice and performance standards made by the Minister of Transport pursuant to the Shipping and Seaman Act 1952, which were published as a supplement to the *New Zealand Gazette* of 26 October 1989 (issue number 190) and dated 31 October 1989.

The requirements for fire appliances including portable fire extinguishers are dependant on the size of the ships and limits of its operation within the coastal limits.

2.9 Health and Safety and Employment Act

The Health and Safety Regulations 1995 apply to all workplaces. These cover facilities required for the safety and health of employees, precautions to be taken with some particular hazards, notification of hazardous construction and forestry work, certificates of competence for some kinds of work, young people in places of work and agricultural workers' accommodation.

The Health and Safety in Employment (HSE)Act 1992[24] reformed the law and provided, for the first time, comprehensive coverage and a consistency of approach to the management of safety and health in all New Zealand workplaces. The Act requires that every employer shall take all practicable steps to ensure the safety of employees while at work. These include to provide and maintain a safe working environment, provide and maintain facilities for the safety and health of employees at work, ensure that plant and machinery and equipment in the place of work is designed, made, set up, and maintained to be safe for employees, ensure that systems of work do not lead to employees being exposed to hazards in or around their place of work and develop procedures for dealing with emergencies that may arise while employees are at work.

The Act has provisions for Approved Codes of Practice that apply to all workplaces. These guidelines contain the best guidance available under the HSE Act[24]. Some of the guidelines that relate to the provision of fire extinguishers include the provision of facilities and general safety in the construction industry, approved code of practice for demolition work, approved code of practice for health and safety in forest operations, guidelines for the provision of facilities and general safety in commercial and industrial premises, guidelines for the provisions of facilities and general safety in the healthcare industry, hazardous goods storage facilities. Some of these guidelines are included in Appendix B of this document.

3 Prescriptive Requirements outside New Zealand

As a part of this research prescriptive codes outside New Zealand have been compared with New Zealand regulations. These include Buildings Codes of Australia, United Kingdom, European Union and the United States of America. The objective was to understand if New Zealand regulations lagged behind other countries and if there was a need to revise the current regulations.

3.1 Australia

The Building Code of Australia (BCA)[25] is produced and maintained by the Australian Building Codes Board (ABCB) on behalf of the Australian Government and State and Territory Governments. The BCA has been given the status of building regulations by all States and Territories.

The goals of the BCA[25] are to enable the achievement and maintenance of acceptable standards of structural sufficiency, safety (including safety from fire), health and amenity for the benefit of the community now and in the future. These goals are applied so that the BCA extends no further than is necessary in the public interest, are cost effective, easily understood, and are not needlessly onerous in its application.

The BCA[25] contains technical provisions for the design and construction of buildings and other structures, covering such matters as structure, fire resistance, access and egress, services and equipment, and certain aspects of health and amenity.

Deemed to satisfy provisions of the BCA[25] 2008 require the provision of fire fighting equipment. Part E1.6 Portable Fire Extinguishers requires the installation of suitable portable fire extinguishers, where necessary to address specific hazards.

Table E1.6 sets out when portable fire extinguishers are required in a building and the class of extinguisher to be used. The installation of portable extinguishers must be in accordance with sections 1, 2, 3 and 4 of AS 2444.

Table E1.6 amended by Amdt No. 11

Table E1.6 REQUIREMENTS FOR EXTINGUISHERS (Note 3)

Occupancy class	Risk class (as defined in AS 2444)
General provisions—Class 2 to 9 (except within *sole-occupancy units* of a Class 2 or 3 building or Class 4 part or *sole-occupancy units* in a Class 9c *aged care building*)	(a) To cover Class AE or E fire risks associated with emergency services switchboards. (Note 1) (b) To cover Class F fire risks involving cooking oils and fats in kitchens. (c) To cover Class B fire risks in locations where flammable liquids in excess of 50 litres are stored or used (not including that held in fuel tanks of vehicles). (d) To cover Class A fire risks in normally occupied *fire compartments* less than 500 m^2 not provided with fire hose reels (excluding *open deck carparks*). (e) To cover Class A fire risks in classrooms and associated corridors in primary and secondary schools not provided with fire hose reels.
Specific provisions (in addition to general provisions)— (a) Class 9a *health care building* (b) Class 3 parts of detention and correctional occupancies (c) Class 3 accommodation for children, aged persons and people with disabilities (d) Class 9c *aged care buildings*	To cover Class A and E fire risks. (Note 2)

Notes

1. For the purposes of this Table, an emergency services switchboard is one which sustains emergency equipment operating in the emergency mode.
2. A Class E fire extinguisher need only be located at each nurses, supervisors station or the like.
3. Additional extinguishers may be required to cover fire risks in relation to special hazards provided for in E1.10.

Figure 3.1: Extract from the Deemed-to-satisfy provisions ABC 2008

3.2 United Kingdom

3.2.1 Building Regulations

Communities and Local Government is responsible for building regulations, which exist to ensure the health and safety of people in and around buildings, and the energy efficiency of buildings. The regulations apply to most new buildings and many alterations of existing buildings in England and Wales, whether domestic, commercial or industrial.

Practical guidance on ways to comply with the functional requirements in the Building Regulations is outlined in a series of "Approved Documents"[26, 27] published by Communities and Local Government. These documents contain general guidance on the performance expected of materials and building work in order to comply with each of the requirements of the Building Regulations and practical examples and solutions on how to achieve compliance for some of the more common building situations.

Both the Approved Documents, Volume 1 – Dwelling houses[26] and Volume 2 – Buildings other than dwelling houses[27] do not specify any requirement for fire extinguishers within buildings.

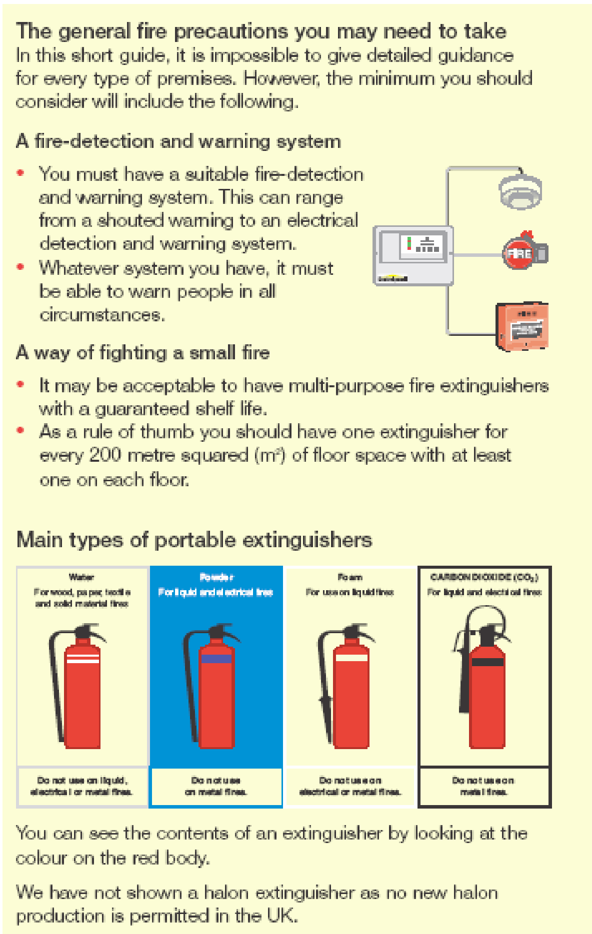
3.2.2 Regulatory Reform (Fire Safety) Order 2005

The Government of UK is committed to regulating only where necessary and in a way that is more suited to the needs of modern businesses and processes. Therefore it introduced the Regulatory Reform Order 2005[28] under the Regulatory Reform Act 2001. It replaced most fire safety legislation with one simple order which enforces that any person who has some level of control in a premises must take reasonable steps to reduce the risk from fire and make sure people can safely escape if there is a fire.

This order is applicable to most buildings except people's private homes, including individual flats in a block or house. Under this order anyone who has control over the premises or anyone who has a degree of control over certain areas is a responsible person and required to meet the requirements. The responsible person could be the employer, the managing agent / owner or the occupier. However when the premises is occupied, there may be more than one person deemed responsible.

This order requires the responsible person to make general fire precautions in which it is required to provide multi-purpose fire extinguishers as a way of fighting a small fire. This order is enforced by the fire authorities by way of inspections, complaints and investigations post fires. If the premises does not meet the order the fire authority will provide advice or in cases of high risk, a formal notice.

Figure 3.2 below is an extract from the Regulatory Reform Order 2005.


The general fire precautions you may need to take

In this short guide, it is impossible to give detailed guidance for every type of premises. However, the minimum you should consider will include the following.

A fire-detection and warning system

- You must have a suitable fire-detection and warning system. This can range from a shouted warning to an electrical detection and warning system.
- Whatever system you have, it must be able to warn people in all circumstances.

A way of fighting a small fire

- It may be acceptable to have multi-purpose fire extinguishers with a guaranteed shelf life.
- As a rule of thumb you should have one extinguisher for every 200 metre squared (m^2) of floor space with at least one on each floor.

Main types of portable extinguishers

You can see the contents of an extinguisher by looking at the colour on the red body.

We have not shown a halon extinguisher as no new halon production is permitted in the UK.

Figure 3.2: Extract from "A Short Guide to Making your Premises Safe from Fire"

3.3 United States of America

NFPA 101[29] also referred as the Life Safety Code®, addresses those construction, protection, and occupancy features necessary to minimize danger to life from fire, including smoke, fumes, or panic. The Code establishes minimum criteria for the designs of egress facilities so as to allow prompt escape of occupants from buildings or, where desirable, into safe areas within buildings. The Code addresses other considerations that are essential to life safety in recognition of the fact that life safety is more than a matter of egress. The Code also addresses protective features and systems, building services, operating features, maintenance activities, and other provisions in recognition of the fact that achieving an acceptable degree of life safety depends on additional safeguards to provide adequate egress time or protection for people exposed to fire. 1.1.5* Considerations Not Related to Fire. The Code also addresses other considerations that, while important in fire conditions, provide an ongoing benefit in other conditions of use, including non-fire emergencies.

The Code does not address general fire prevention or building construction features that are normally a function of fire prevention codes and building codes, prevention of injury incurred by an individual due to that individual's failure to use reasonable care and preservation of property from loss by fire.

Section 9.7.4 requires the provision of manual extinguishing equipment where required.

9.7.4 Manual Extinguishing Equipment.

9.7.4.1* Where required by the provisions of another section of this *Code*, portable fire extinguishers shall be installed, inspected, and maintained in accordance with NFPA 10, *Standard for Portable Fire Extinguishers*.

9.7.4.2 Where required by the provisions of another section of this *Code*, standpipe and hose systems shall be provided in accordance with NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*. Where standpipe and hose systems are installed in combination with automatic sprinkler systems, installation shall be in accordance with the appropriate provisions established by NFPA 13, *Standard for the Installation of Sprinkler Systems*, and NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*.

Figure 3.3: Extract from NFPA 101

4 Fire Incident Statistics in New Zealand

4.1 New Zealand Fire Service FIRS data

Every emergency incident attended by the New Zealand Fire Service or the Rural Fire Authorities requires that the officer in charge complete a form summarizing the important features of the incident. These incidents are processed and audited before they are incorporated into an incident database (NZFS-FIRS[30] database) which is a dynamic database, which allows emergency incident information to be update/edited anytime.

This data is used in research projects directed at fire safety improvements to building standards and codes, consumer products and community safety programmes for delivery by the Fire Service Staff or for multi-agency campaigns.

As mentioned before, the SMS Incident System (NZFS-FIRS[30] database) is a dynamic database. Most of the data is kept within the Fire Service and stored for historical purposes. A procedure similar to a Census, which provides emergency incident information at any given time. Using specialized software, this data cube is processed and emergency incident information is published on a yearly basis that contains various tables of statistical information.

This research has used some of this statistical information to analyze the incidence of fires in different occupancies. This has been done to filter some specific occupancies and analyse them for cost benefit analysis. It is understood that some occupancy types will use extinguishers as a part of their routine since the processes involves fire risk management; for example some metal fabrication industries have shown a higher incidence of use of portable extinguishers due to the nature of the work being done on the shop floor. On the other hand there are occupancies where it may be necessary for the staff to use extinguishers on small fires to contain and extinguish them and therefore prevent total evacuation of the premises; examples where such a system is used is Hospitals, rest homes, motels and hotels. There are the other occupancies like commercial and retail buildings where the buildings may be provided with portable devices but the use of these equipment may not happen due to lack of trained personnel.

The following pages display the information available from the Fire Service database. The charts shown in the pages ahead have been produced using data from the NZFS-FIRS[30] database.

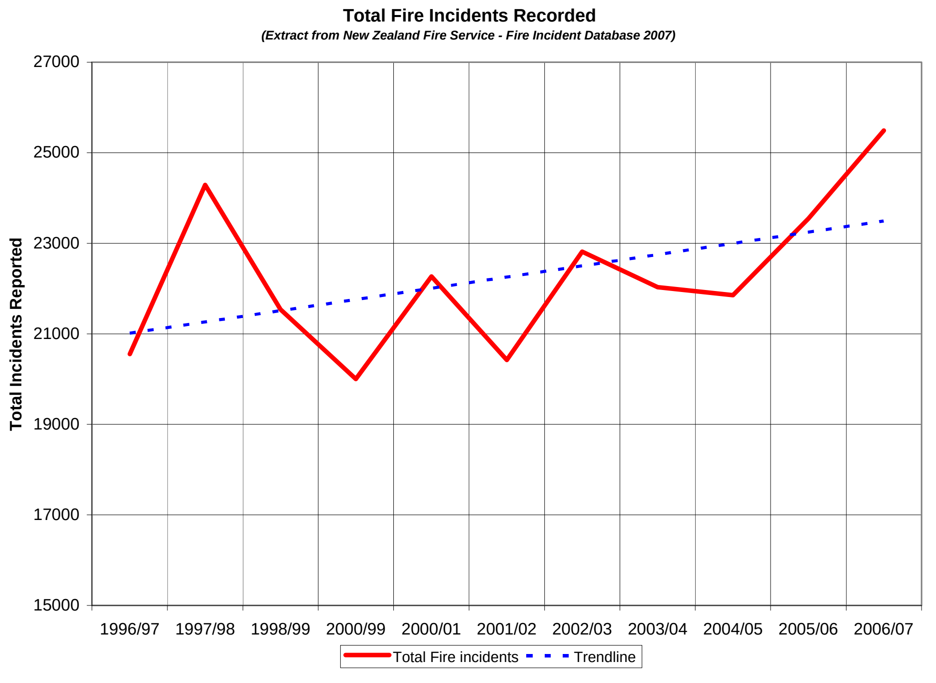


Figure 4.1: Total Number of Fire Incidents Reported in New Zealand

The total number of fire incidents recorded shows an increase over the years.

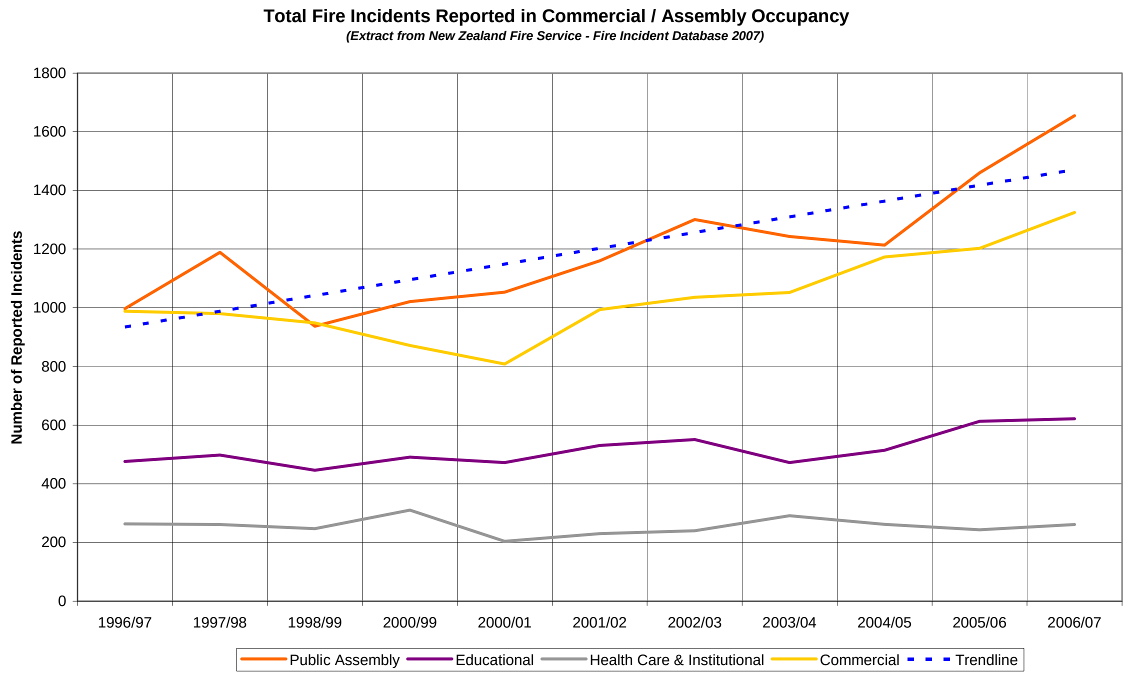


Figure 4.2: Total Incidents Reported in Commercial/Assembly Occupancy

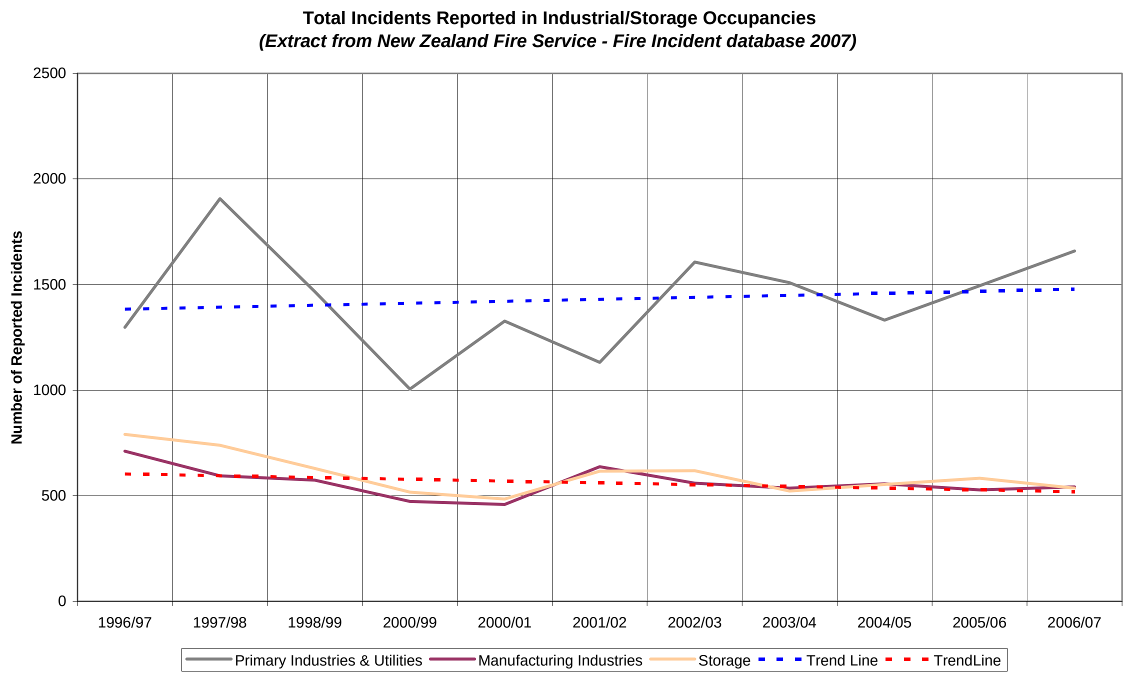


Figure 4.3: Total Incidents Reported in Industrial / Storage Occupancy

Figure 4.2 and 4.3 shows the number of fire incidents recorded in non residential buildings. The number of incidents in commercial and public assembly buildings has shown a steady increase over the years, the recorded incidents numbers being 10% of the total incidents recorded. The number of incidents in educational and health care facilities remains to be steady with a contribution of 9% of the recorded incidents. The highest number of incidents recorded in public places was in recreational place with variable use; 74%.; highest number of incidents recorded in commercial places was in food and beverage outlets at 38%, and offices recording at 14%.

The rate of fire incidents in primary industries and utilities has see sawed over the years giving a steady rate of increase. Fire incidents recorded in manufacturing industries and storage occupancies has been on a decline. The total contribution of these occupancies is at 11% of the total incidents reported.

The highest number of incidents recorded was from residential occupancies at 31%. See figure 4.4 for the distribution.

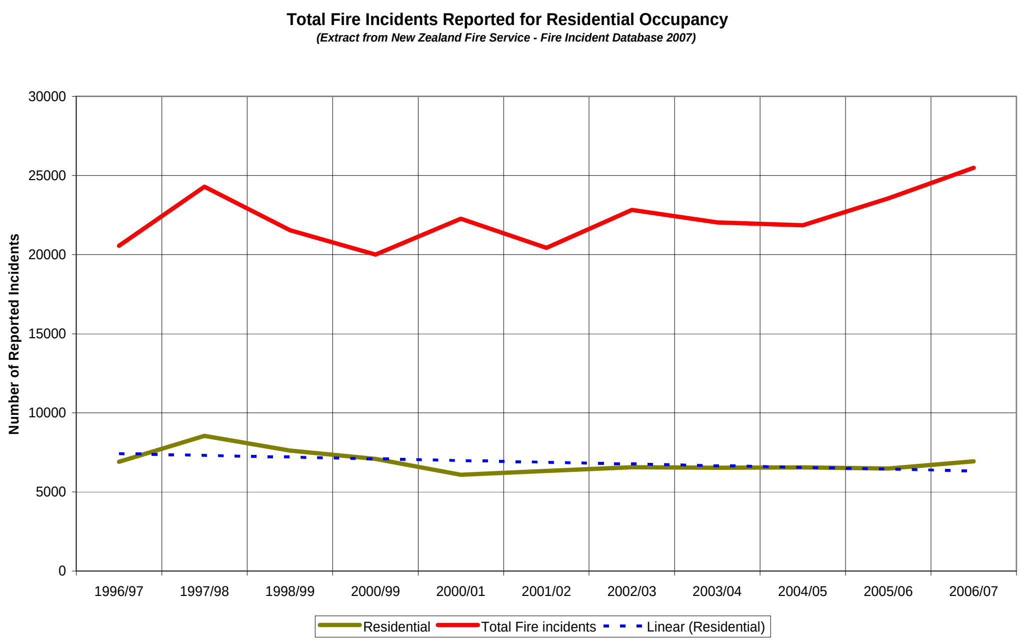
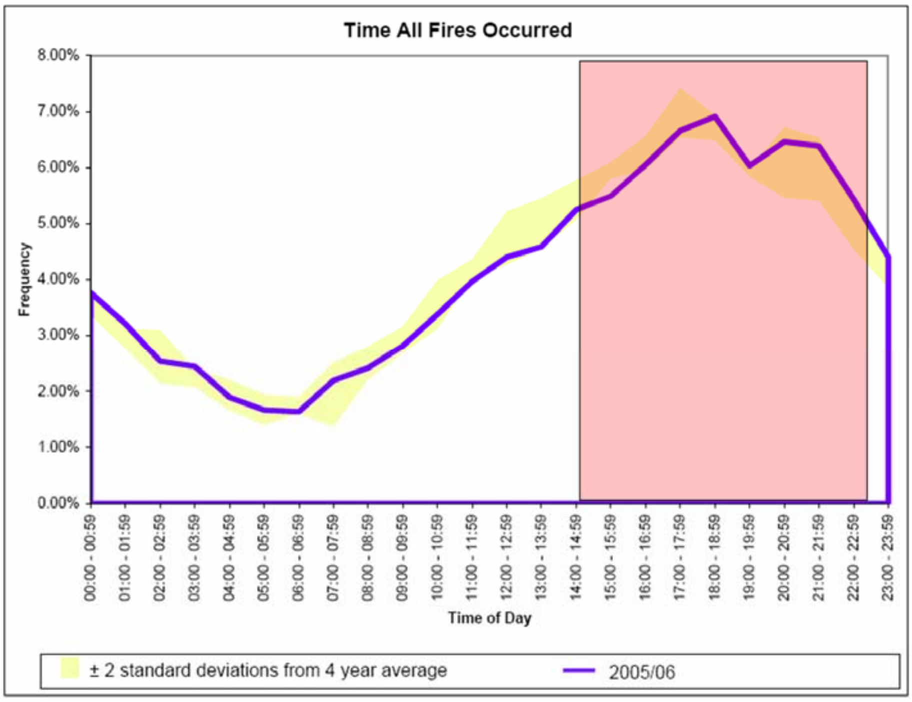


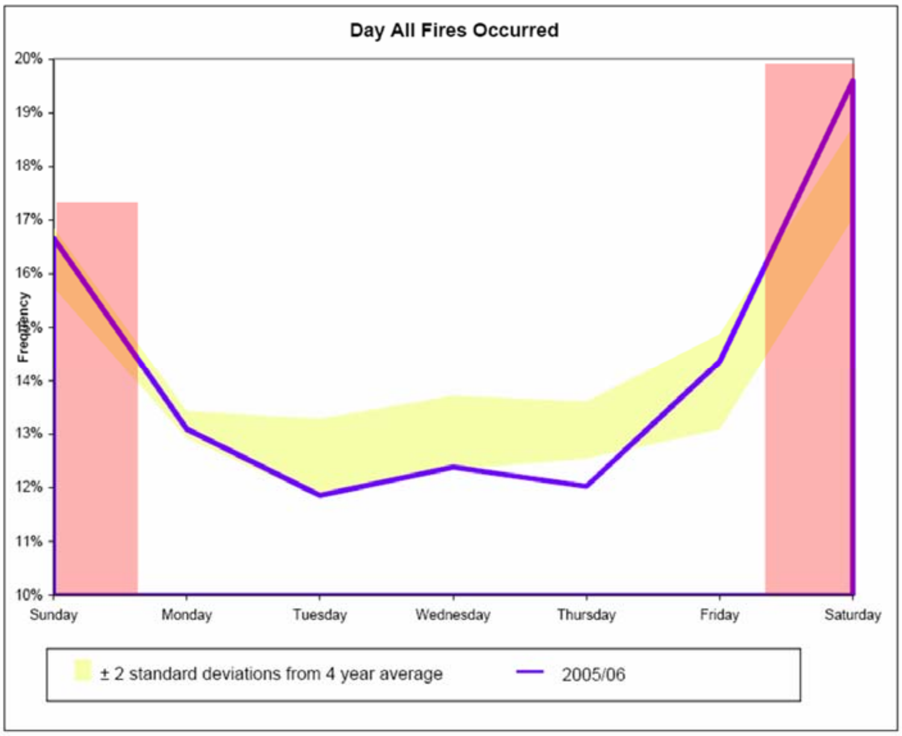
Figure 4.4: Total Incidents Reported in Residential Occupancy

The NZFS-FIRS [30] database also records the time and day of the incident.



Graph extracted from the NZFS-FIRS Database 2006-07

Figure 4.5: All times fires occurred



Graph extracted from the NZFS-FIRS Database 2006-07

Figure 4.6: All days fires occurred

Figure 4.5 and 4.6 are representations of time and day of fire incidents recorded. The graphs indicate that most fires have been recorded on the weekends and between 2:00 PM and 11:00 PM in the day. Figure 4.5 and 4.6 has been adapted from the data available in the NZFS-FIRS [30] database.

The NZFS-FIRS database[30] holds data regarding the reported use of extinguishers and hose reels in a fire incident. The use of extinguishers recorded is for containment of the fire. This report records the use of extinguishers and/or hose reels by occupants /passer by's and the fire service personnel to control the fire.

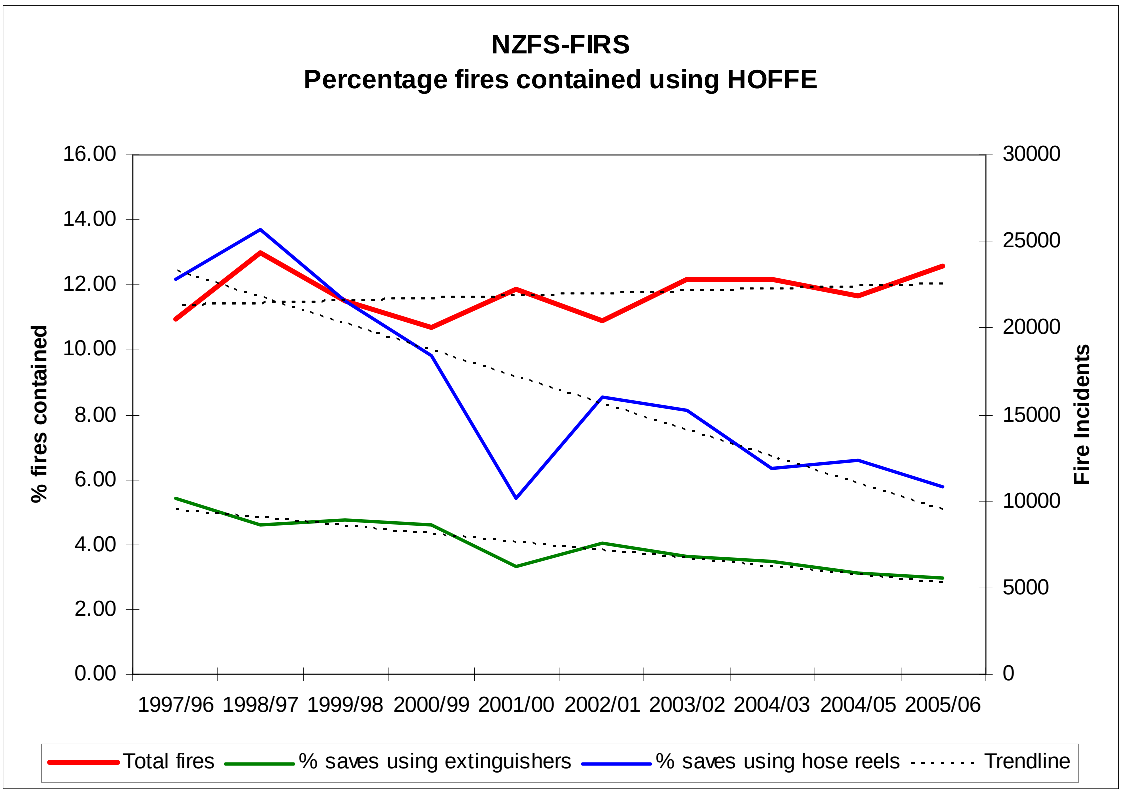


Figure 4.7: Fire Incidents Contained Using HOFFE

Figure 4.7 analyses the percentage use of Hand Operated Fire Fighting Equipment (HOFFE) to contain fires. The data set used to define "% saves using hose reels" also includes the use of garden hoses which have been used to contain a fire. Figure 4.7 shows that the trend in the use of extinguishers and hose reels is on the decline over the years. However this database only records incidents in which the fire service has been involved. More accurate data for extinguishers and hose reels may be available from sales and service agencies dealing in fire extinguishers and fire systems maintenance.

5 Fire Extinguisher Usage Survey

As identified in section 4 before, the incidence of use of portable fire extinguishers is recorded in the NZFS-FIRS[30] database. This data is based on incidents that are attended by the New Zealand Fire Service (NZFS) and therefore may not represent the accurate and complete usage of fire extinguishers in New Zealand. A more accurate representation will emerge from a survey carried out by the fire protection industry as they would be aware of fire extinguisher usage as a part of their service requirements. Many building owners may not report minor fires that have been controlled using an extinguisher to the NZFS because they feel that it was not required to or because it is a part of daily operations of their business (for e.g. the foundry industry may use portable fire extinguishers as a part of their daily operations but may not want to report every incidence of usage).

These surveys are carried out in association with the Fire protection Association of New Zealand (FPANZ) which represents the fire protection industry and will be able to muster support from the industry for the surveys and represent the industry if the survey results were to be used for a change in legislation.

5.1 New Zealand Fire Service / FPANZ Survey 2003-04

In 2003/04 the Fire Service as a part of developing a Code of Practice for Hand Operated Extinguishers was looking for data on the use of extinguisher by building occupants. They too felt that the data provided within the NZFS-FIRS[30] database was not a complete representation of the actual use of fire extinguishers. The purpose of the Code of Practice for Hand Operated Extinguishers was to become a document of reference when addressing the requirements, under regulation 10(2) of the Fire Safety and Evacuation of

Buildings Regulations 1992, for building owners or tenants to install and maintain portable fire extinguishers within their building.

The survey[31] data was collected for approximately 8 months (Oct 03 – May 04) and reported a total of 395 extinguishers used. The Fire Service interpreted the data collected as below.

- In 90% of the known incidents where fire extinguishers are used, the Fire Service is not called
- In approximately 83% of cases, portable fire extinguishers are totally effective.

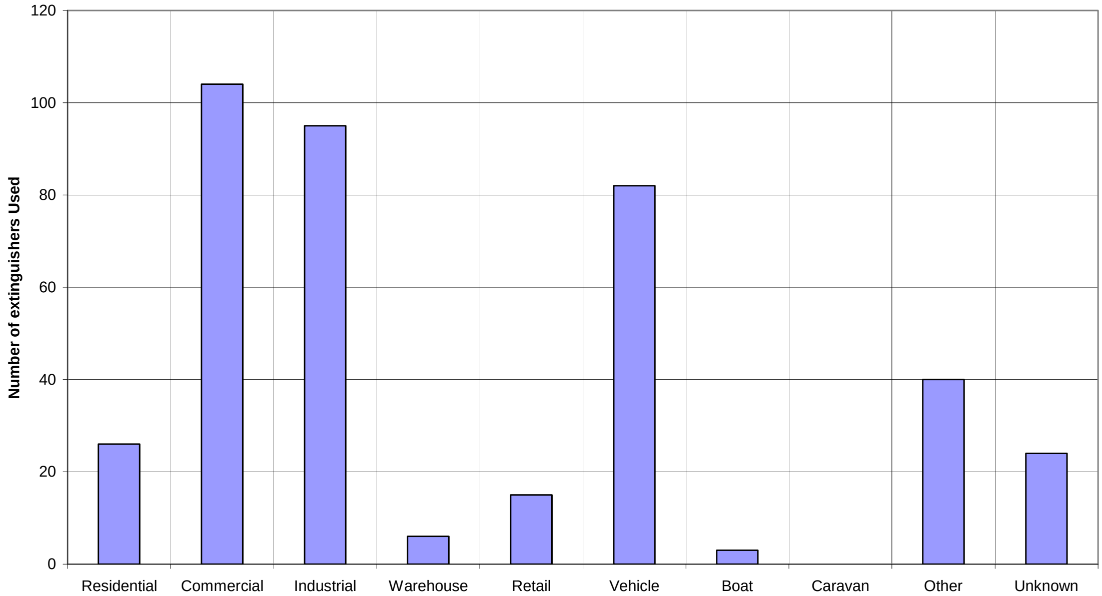


Figure 5.1: Fire Extinguishers used by Occupancy

Figure 5.1 represents the number of extinguishers used in each occupancy type.

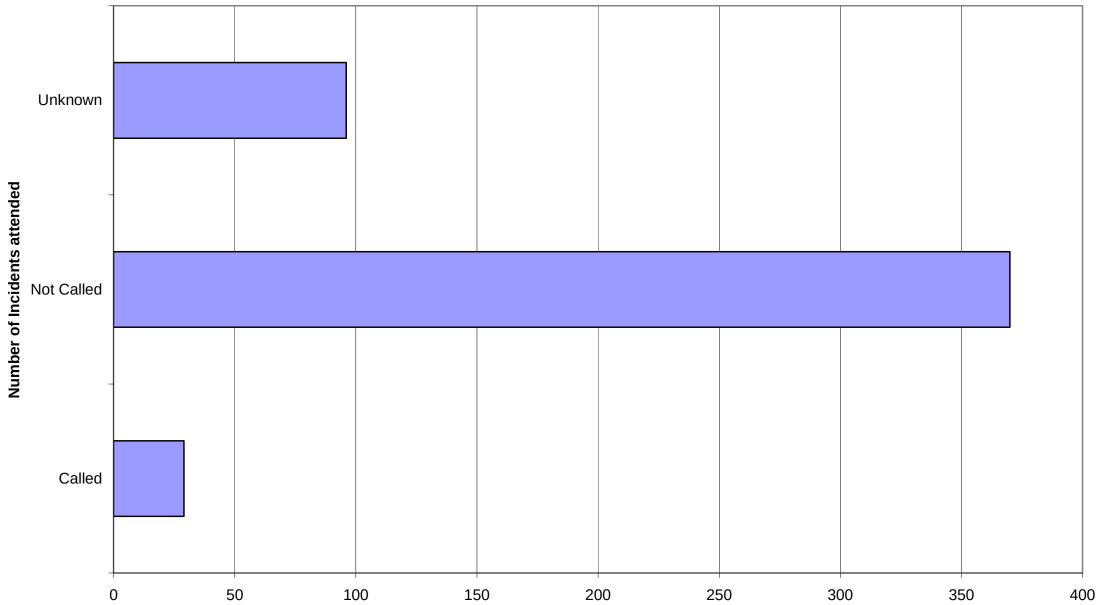


Figure 5.2: Fire Service Attendance

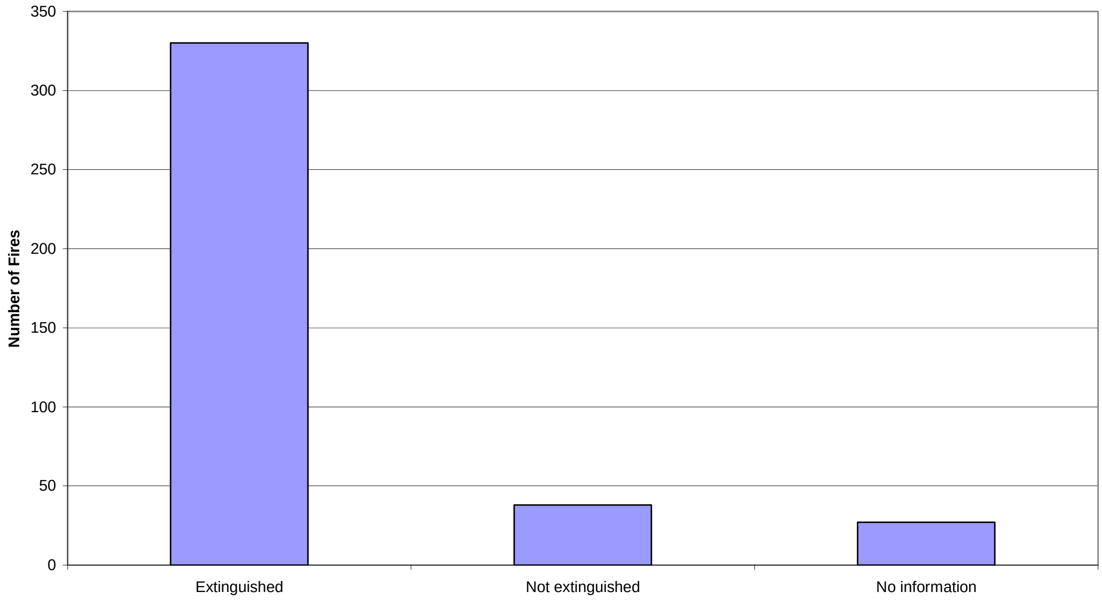


Figure 5.3: Fire Extinguisher Effectiveness

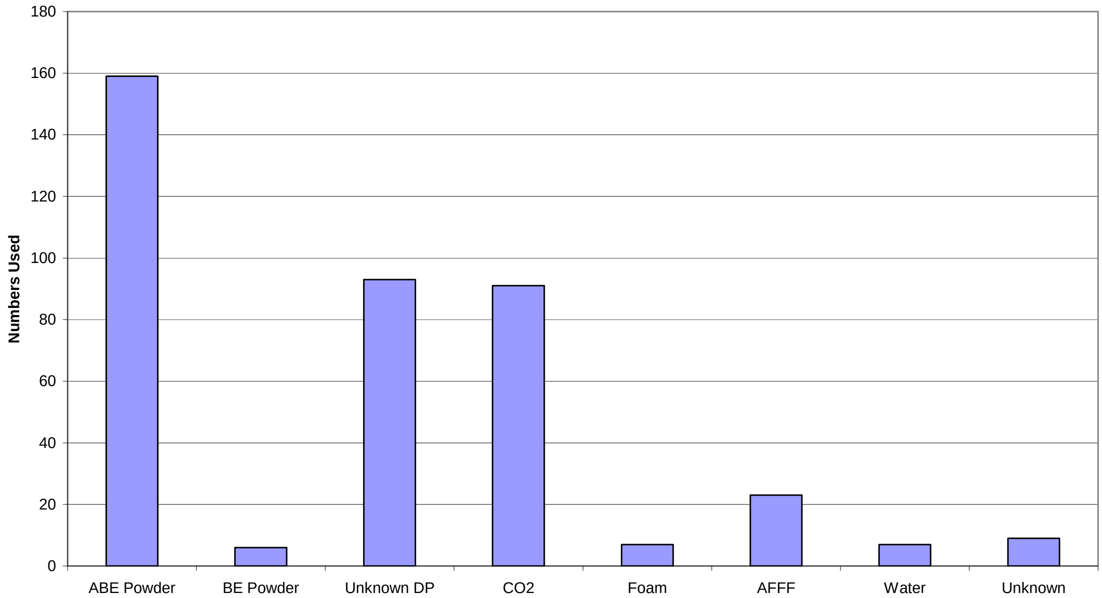


Figure 5.4: Type of Fire Extinguisher Used

The New Zealand fire service carried out statistical modelling of the data from the survey and concluded that the survey results did not represent actual extinguisher usage in New Zealand. The primary reasons for the failure were stated to be the following:

- Insufficient sample size (not enough agents returning survey forms)
- Inconsistent returns (agents not completing a form for every month)
- Uneven distribution of survey forms (many areas of the country were not represented)
- Uneven weighting of returns (large number of returns from some areas versus small number of returns from other areas – especially in larger centres, resulting in bias)

However the available data has provided some valuable information especially in the effectiveness of extinguishers and the potential to reduce Fire Service callouts. It will be worthwhile to see if a similar result is reached in future surveys.

5.2 University of Canterbury / FPANZ Survey 2008

The scope of the survey was to get feedback from the fire protection industry regarding fire incidents where fire extinguishers may have been used. This part of the research project was conducted with assistance from the Fire Protection Association of New Zealand (FPANZ).

The survey was run for a period of 4 months between May 08 and August 08. The time period of 3 – 4 months was considered to be appropriate for collection of data and carry out statistical modeling. This time period is similar to the one used in the UK survey in 2002. Discussions with the statisticians at the New Zealand Fire Service also considered 3 – 4 months as a suitable time period for data collection.

This survey was aimed at all members of the FPANZ members that carried out servicing & maintenance of extinguishers. As determined by the 2002 survey in UK, not all minor fire incidents are reported to the Fire Service therefore they do not feature in official statistics. This survey was aimed at determining the estimates of fire incidents that are minor and have been contained by extinguishers which might not be reported to the Fire Service. It is understood that service agencies would have direct access to such data since they would be involved in refilling extinguishers after a minor incidents. As a part of the survey an information pack was emailed / mailed to the large fire protection companies based in Auckland, Wellington and Christchurch. The information pack was also made available on the FPANZ website for download. Details of the information pack & survey forms are available for reference in Appendix D. The final survey results are provided below.

5.2.1 Monthly Summary

The monthly summary is specific to incidents recorded each month. Extinguishers that have been maliciously used have been identified and recorded specifically and are not included in the calculation of effectiveness. Injuries and fatalities have been included based on reports from fire service (where the fire service has attended the incident). Some incidents reported in the press (which provide details of extinguisher usage) are also included.

	May	June	July	August
Total Recorded incidents	29	48	39	28
Total number of extinguishers used on a fire	31	56	42	33
Maliciously / accidentally discharged	0	3	1	0
Injuries recorded	0	1	1	0
Fatalities recorded	0	0	0	0
Contributing Companies	2	3	3	3
Contributing regions	5	7	6	5

Table 5.1: Monthly summary of survey results

5.2.2 Summary of Results – Survey 2008

Total number of Fire Incidents Recorded	144	
Total Number of extinguishers Used	162	
Extinguisher Used by Occupancy		% of reported incidents
Residential	11	7.64
Commercial	36	25.00
Health Care	1	0.69
Education	6	4.17
Warehouse	1	0.69
Retail	6	4.17
Industrial	58	40.28
Vehicle	13	9.03
Caravan	2	1.39
Boat	6	4.17
Others	4	2.78
		% of used extinguishers
Maliciously Discharged	4	2.47
Extinguisher Effectiveness		
Fires extinguished by extinguisher	136	
Fires partially extinguished by extinguisher	4	
Fires re-ignited	1	
Not Extinguished - Fire too Large	3	
Not Extinguished - Wrong Extinguisher Used	0	
Effectiveness percentage	94	%
Extinguishers Used By		% of reported incidents
Owners / Occupiers	124	86.11
Passers By / Others	10	6.94
Fire Service	4	2.78
Unknown	6	4.17
Fire Brigade Calls made	16	
% incidents attended by fire service	11.11	
% incidents where fire service not called	88.89	
Estimated Losses in NZ$	14915	(where reported to the service agency)

Injuries Reported	2
Fatalities Reported	0

5.2.3 Graphical Analysis

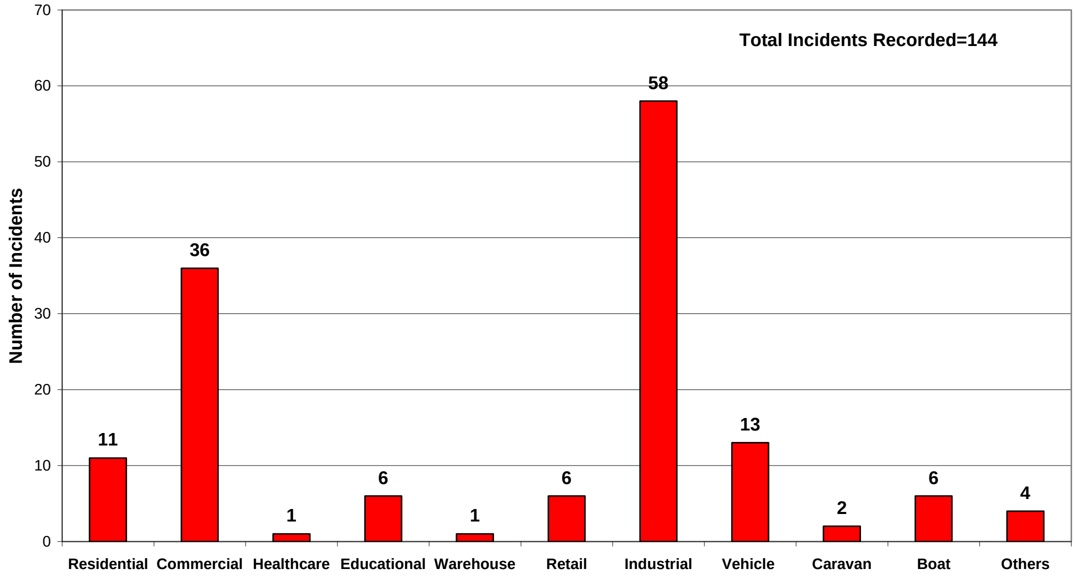


Figure 5.5: Number of Fire Incidents Recorded (Survey 2008)

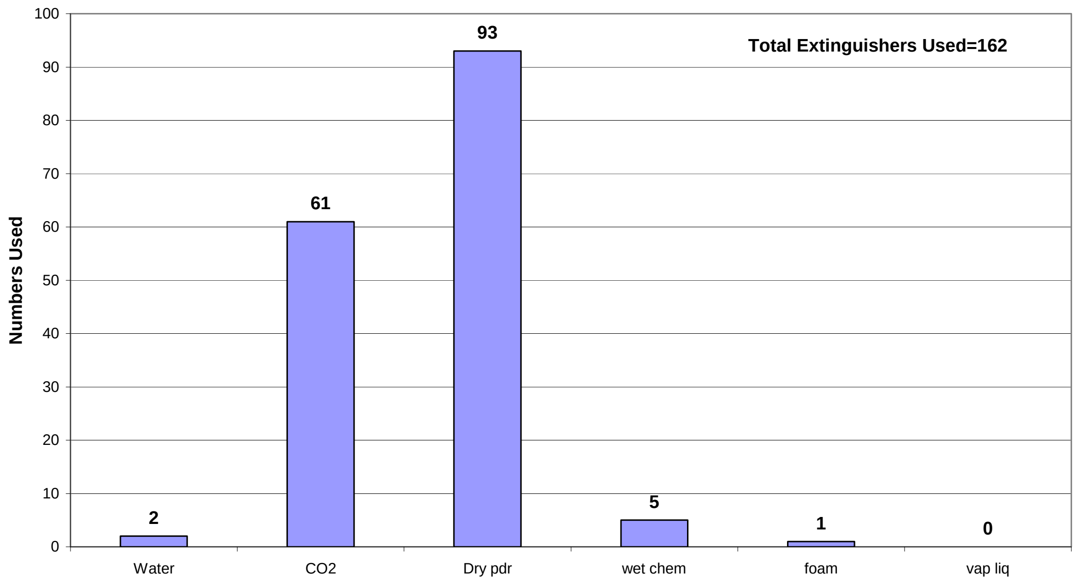


Figure 5.6: Type of Fire Extinguisher Used (Survey 2008)

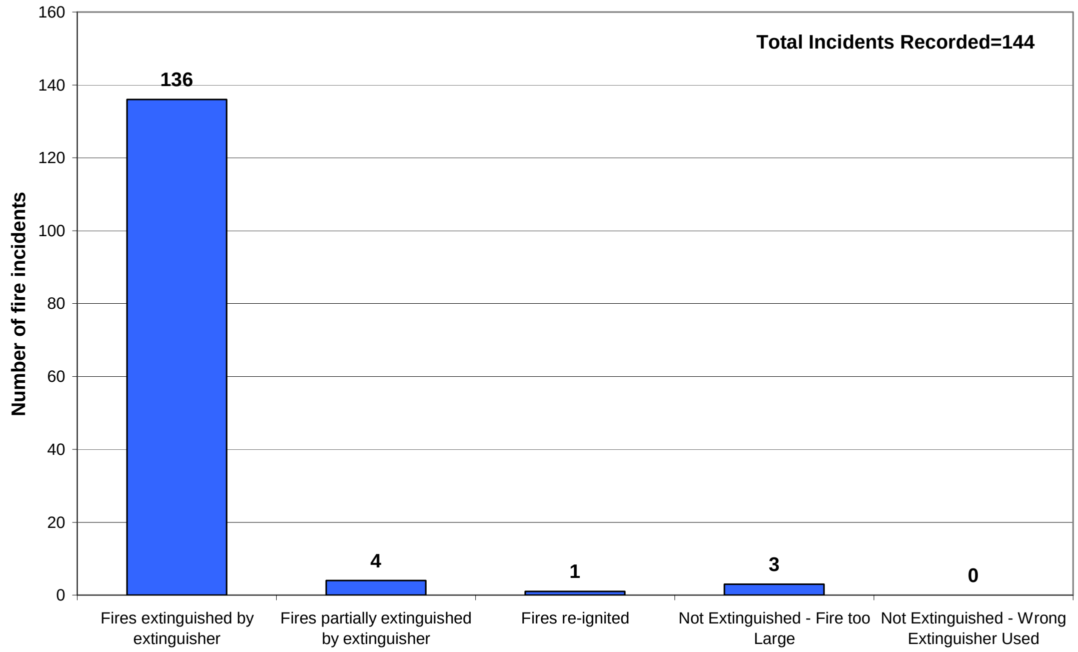


Figure 5.7: Fire Extinguisher Effectiveness (Survey 2008)

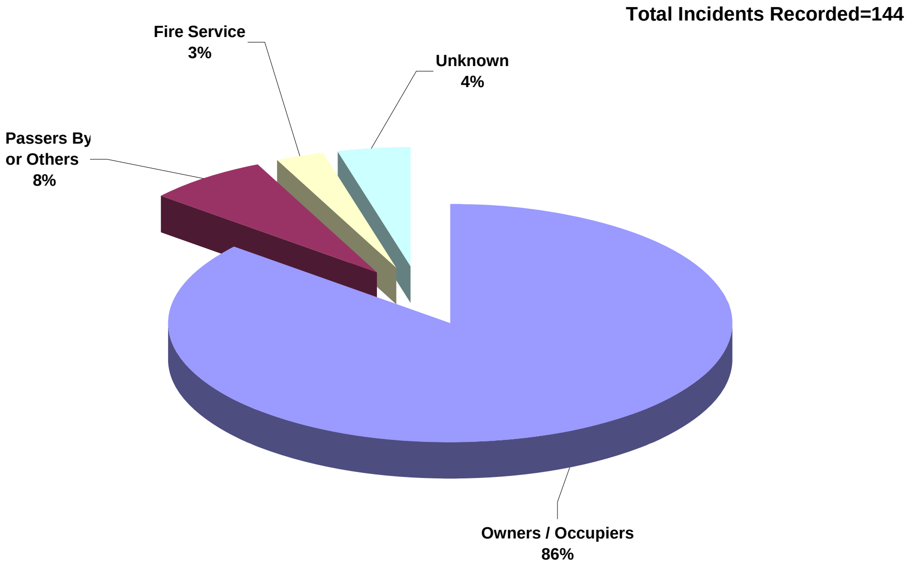


Figure 5.8: Extinguisher Used By (Survey 2008)

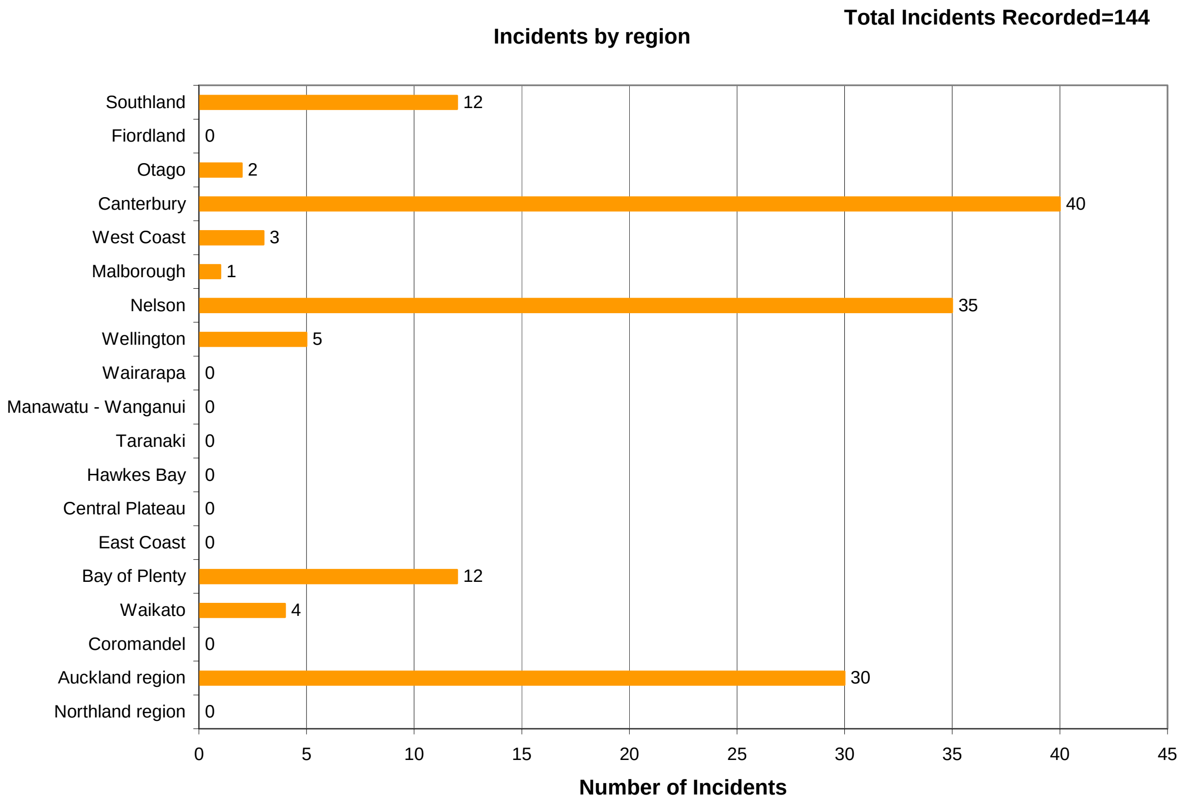


Figure 5.9: Incidents Recorded by Region (Survey 2008)

5.2.4 Conclusions from Survey

The data collected from the survey is interpreted as follows.

- In approximately 94% of the incidents recorded, a portable fire extinguisher is totally effective in containing & suppressing a minor fire.
- In 89.9% of the known incidents where fire extinguishers are used, the Fire Service has not been called.
- In approximately 86% of the incidents a fire extinguisher was used by the building owner / occupier.
- Approximately NZ$ 14915 was recorded as damage from the recorded 144 fire incidents. This would give an average NZ$ 104 per incident. This information was not provided for a small proportion of incidents.

However the survey cannot be used for making statistical recommendations because of the following reasons.

- Uneven distribution of feedback received (many areas of the country were not represented)
- Uneven weighting of returns (large number of returns from some areas versus small number of returns from other areas – especially in larger centres, resulting in bias).
- Not all fire protection companies participated in the survey (many areas of the country are not be represented).

One positive outcome is that the results of the 2008 survey is very closely aligned to the 2003-04 survey[31] and is also comparable to the European 2002 survey[10]. Although sufficient data was not collected in the survey, a general tend can be established which confirms that within New Zealand, extinguishers are successfully used by building owners/occupants to contain minor fires and a large proportion of these incidents are not reported to the Fire Service, therefore do not get included in the official statistics.

6 Risk Analysis

6.1 What is Risk?

AS/NZS 4360[32] defines risk as "The chance of something happening that will have an impact on objectives". Risk may have positive or negative effect and is measured in terms of consequences and likelihood.

Risk is inherent in everything we do. In general, we take a risk in order to benefit from an opportunity. When we consider opportunities, we weigh up the risks, look at the benefits we might achieve, and make our decisions accordingly. The purpose of risk management is to apply a process to identify risks, set an acceptable level for risk, and take steps to keep residual risk at acceptable level. An acceptable level of risk is influenced by legal requirements (established legislation etc), personal risk tolerances and societal views. Risk is managed by developing appropriate responses to reduce consequences of adverse incidents, their likelihood, or both. This is achieved by proper identification of risks and hazards, assessment of consequences and likelihood and development of a response plan.

This project has looked at the risk of fire in a building, potential consequence in terms of loss of life, property protection and business interruption and generated a risk model to evaluate cost benefit analysis of fire safety features to contain and fight a fire.

6.2 Risk Informed Performance based Fire Protection

Risk informed performance based fire protection[33] is an integration of decision analysis and quantitative risk assessment with a defined approach for quantifying the performance success of fire protection systems (FPS).

Evaluation tools and techniques like event trees etc has been used to do a quantitative risk assessment (QRA) in conjunction with traditional fire protection modelling tools. The performance based fire protection is a quantitative, probabilistic measure of fire protection success based on functional performance requirements derived from specific scenario and risk tolerance criteria. Performance is evaluated within an event tree risk model on a conditional probability basis that is equated by three primary factors: Response effectiveness, online availability and operational reliability

In risk-based decision making, RISK is understood in terms of the likelihood and consequence of incidents that could expose people, property and the environment to the harmful effects of fire. Likelihood is determined in terms of either frequency (how often can this happen) or probability (what are the chances this will happen)

RISK = Likelihood of Fire Incident (F) x Expected Consequences (C)

Risk associated with multiple initiating event scenarios is the sum of the scenarios…

$$\textbf{RISK} = \Sigma_{sn}\ \textbf{F} \times \textbf{C}$$

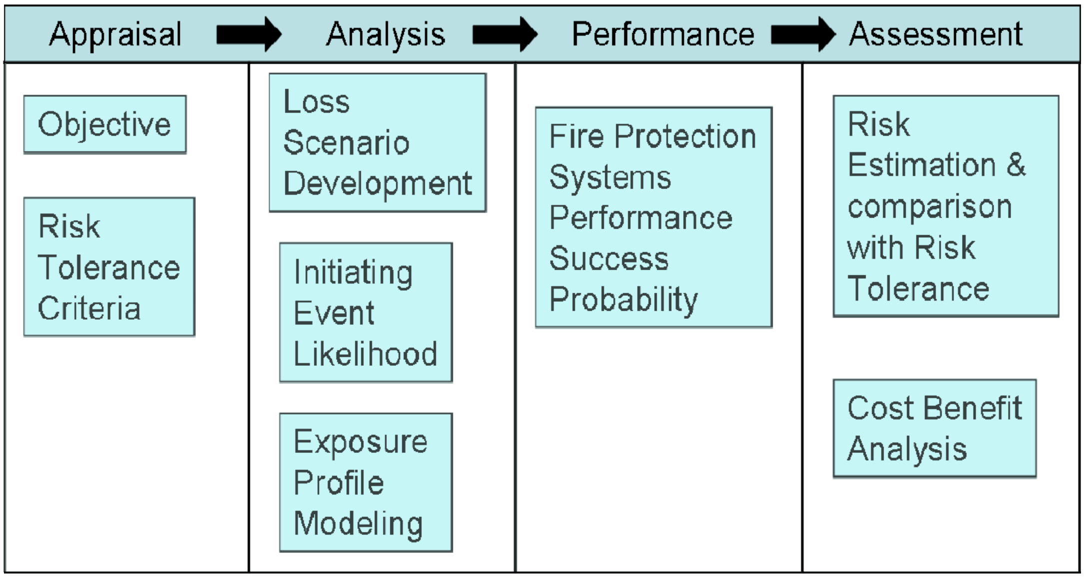


Figure 6.1: Risk Analysis Process

The above equation is for unmitigated risk. For mitigated risk we consider the probability of fire protection system (FPS) performance success. The FPA performance is introduced in the risk equation to be used with the event tree analysis (ETA). The risk equation is therefore modified as below:

$$\mathbf{RISK = \Sigma_{sn}\ F \times P_{FPS} \times C}$$

The FPS performance success is the product of the probabilistic success measures of a fire protection system.

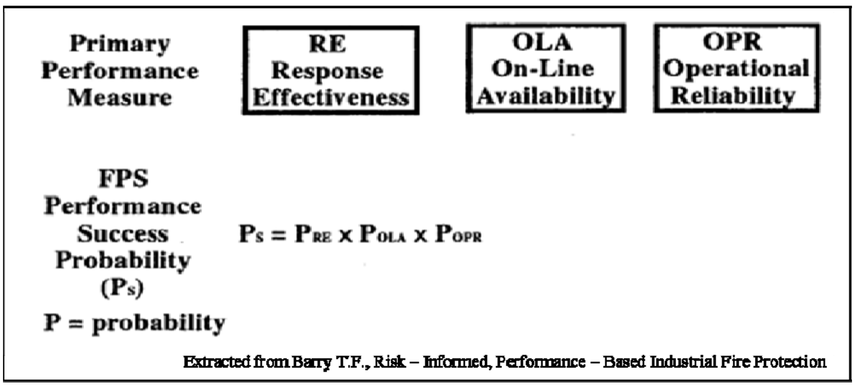


Figure 6.2: Example of primary FPS success measures

6.3 Risk Tolerance Criteria

Risk tolerance criteria provide a quantitative basis against which risk analysis results and risk reduction efforts are measured. Establishing risk tolerance guidelines helps management make consistent, well informed decisions based on risk (likelihood and consequence)

Exposure level risk tolerance has been divided into 3 main categories: Life safety risk tolerance, business interruption risk tolerance and property damage risk tolerance.

The tables below are reproduced from the data provided by Center for Chemical Process Safety, Guidelines for Chemical Process Quantitative Risk Analysis[34]. These tables are a guide as to how risk tolerance levels may be selected. For the purpose of risk modeling in this research we have not used likelihood tolerance data. The following tables are provided as information only and have not been used in this research.

Life safety exposure in a fire condition can be given the following tolerance criteria.

Life Safety Exposure	Potential Consequences	Likelihood tolerance limits (events/year)
1 - Low	Minor First Aid (i.e. smoke inhalation)	0.1
2 - Moderate	Single person injury requiring hospital treatment	0.01
3 - Heavy	Multiple person injuries requiring hospital treatment (1 - 2 people)	1×10^{-3}
4 - High	Potential for multiple injuries, single person death ON-SITE	1×10^{-5}
5 - Very High	Potential for 1 -3 fatalities on site	5×10^{-5}
6 - Extremely High	Potential for multiple injuries, single person death OFF-SITE	1×10^{-6}
7 - Catastrophic	Potential for multiple fatalities - OFF-SITE	5×10^{-6}

Table 6.1: Life Safety Exposure Categories

The description of the potential consequences is based on the data provided by the Centre for Chemical Process Safety, USA.

Business Interruption Levels	Potential Consequences	Production downtime range	Average production downtime days	Likelihood tolerance limits (events/year)
1 - Slight	Limited localized minor equipment damage not requiring repair but clean up	0 -1 days	0.5	0.33
2 - Light	Significant localized damage of some equipment / workflow components	1 -10 days	5	0.1
3 - Moderate	Significant localized damage of many equipment / workflow components	10 - 30 days	20	0.01
4 - Heavy	Heavy damage requiring major repair / replacement of equipment / work areas	30 - 90 days	60	1×10^{-3}
5 - Major	Major widespread damage to multiple floors / work process centers	90 - 270 days	180	5×10^{-3}
6 - Critical	Extensive damage to most of the facility	270 - 365 days	318	1×10^{-4}
7 - Total or Maximum	Maximum downtime expected	1 - 2 years	-	1×10^{-6}

Table 6.2: Business Interruption Levels

Property damage levels	Potential Consequences	Damage factor range (%)	Central damage factor (%)	Likelihood tolerance limits (events/year)
1 - Slight	Limited localized minor equipment damage not requiring repair but cleanup	0 - 1	0.5	0.33
2 - Light	Significant localized damage of some components generally not requiring major repair	1 - 10	5	0.1
3 - Moderate	Significant localized damage of many components warranting repair	1 - 30	20	0.01
4 - Heavy	Extensive damage requiring major repairs	30 - 60	45	1×10^{-3}
5 - Major	Major widespread damage that may result in facility being demolished / repaired	60 - 100	80	5×10^{-5}
6 - Destroyed	Total destruction of the facility	100	100	1×10^{-6}

Table 6.3: Property Damage Levels

The above potential consequences can be evaluated in terms of damage categories which can be related to Equivalent Monetary Values (EMV) to prepare a cost benefit analysis. The above data has been originally based on chemical industries but can be adapted to other occupancies to carry out a risk based analysis.

6.4 Establishing Event Likelihoods and Loss Expectancy

Likelihood ranges are established using a format that lists expected time between occurrences and a qualitative description of these frequency ranges and categories. Loss expectancy is a qualitative estimate of the severity of a defined fire scenario.

First order approximation of likelihood levels are shown below has been adapted from data provided by Center for Chemical Process Safety, Guidelines for Chemical Process Quantitative Risk Analysis[34]

Loss Expectancy Level	General Definition	Guide Word	Likelihood Range
NLE - Normal Loss Expectancy	Nuisance Fire	Likely	1 per 5 years (0.2)
	Design Basis Fires	Likely	1 per 20 years (0.05)
PML - Probable Maximum Loss	Design basis fires with primary protection	Unlikely	10^{-2}
	Systems failure, high challenge fire	Unlikely	10^{-3}
MFL - Maximum foreseeable loss	Worst case - ON SITE	Very Unlikely	10^{-4} - 10^{-5}
	Worst case - OFF SITE	Extremely Unlikely	10^{-5} - 10^{-6}

Table 6.4: First Order Likelihood Levels

The event likelihoods used for the risk model in the next section is based on actual data surveys done for specific occupancies for determining ignition frequency.

7 Risk Model for Evaluating Extinguishers as a Fire Protection System

7.1 Risk Model Approach

The benefits use of portable extinguishers with respect to passive and active fire protection systems (FPS) is being viewed critically by building regulators and design consultants. The primary factor being usage effectiveness and therefore cost benefits to the building owner/occupier when other FPS are provided.

This section examines the provision of fire extinguishers as a first aid fire intervention system along with other active and passive FPS. For this specific study we have considered the following buildings for assessment within this risk model.

7.2 Building Models

The building models are based on the building types listed by the Department of Building and Housing[36] for cost estimates. The Department of Building and Housing provides building costs to assist Territorial Authorities to arrive at realistic estimated values when they have questioned the job value provided with a building consent application. Costing information for these series of building types has been provided by Maltby and Partners Ltd[37], a firm of construction cost consultants. Maltby has priced from a set of authentic construction documents in order to establish a unit cost that is as accurate as possible. These buildings are representative of majority of buildings constructed in New Zealand therefore we have used them in the risk modeling.

These buildings are assumed to be constructed to comply with the requirements of the Compliance Document, C/AS1[1] with respect to the fire safety requirements. The details of these buildings are shown below

7.2.1 Residential Building (House 202 m^2)

This model building is a single-storey house on a flat site that includes an internal double garage, three bedrooms, open-plan kitchen, dining and lounge, bathroom, separate toilet, en-suite, and separate laundry. The building construction comprises of reinforced concrete slab, timber-framed walls and prefabricated timber-trussed roof, brick veneer external cladding, aluminium external joinery, pre-finished steel roof, and plasterboard linings.

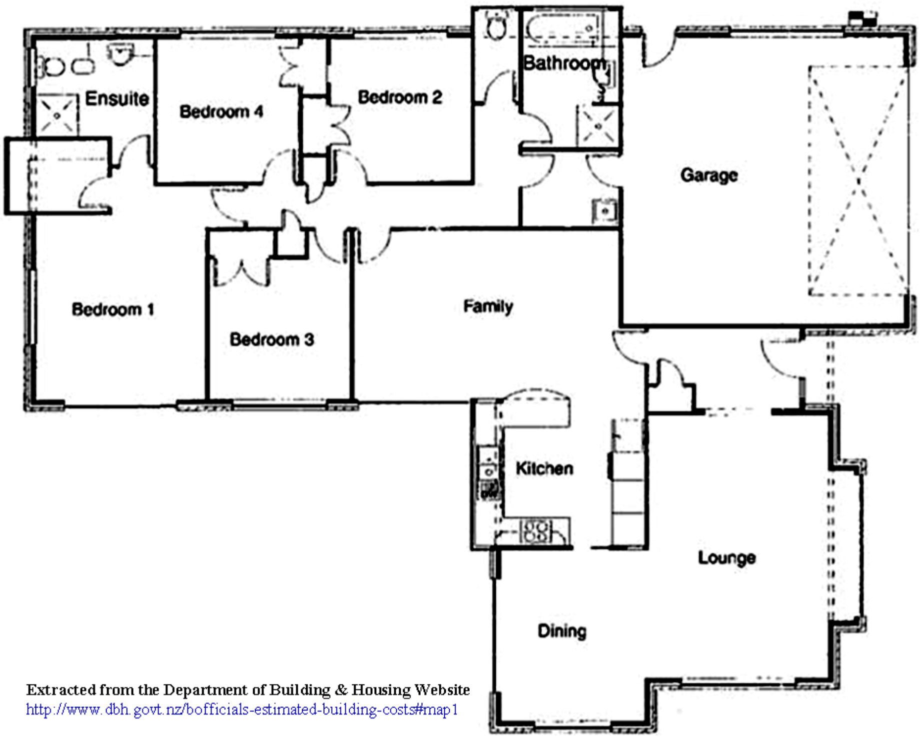


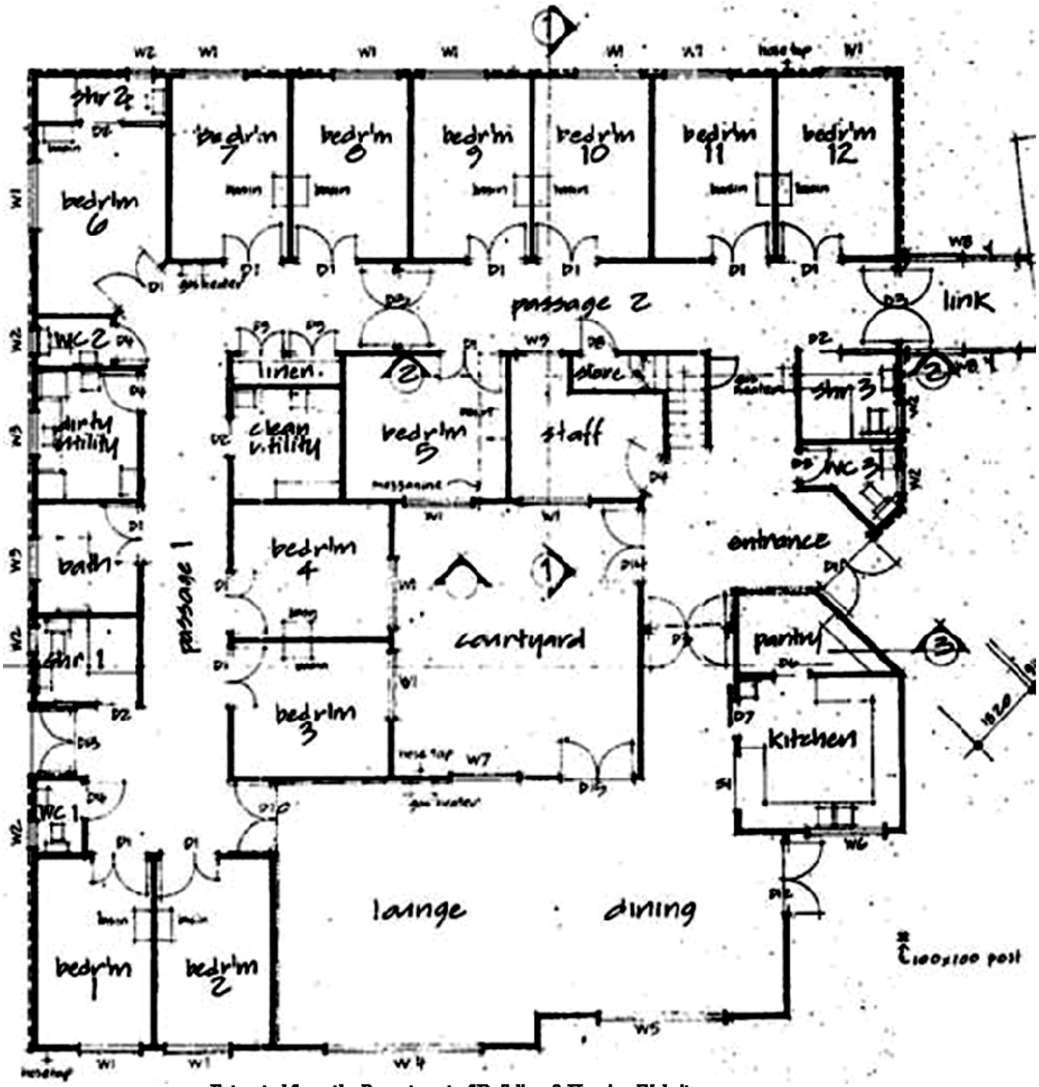
Figure 7.1: Model Residential Building

The building is expected to have occupancy of 5 persons. As per the Compliance Document C/AS1[1], the building is classified as SH, FHC1. SH represents the occupancy purpose group for detached dwellings and FHC is the fire hazard category.

7.2.2 Care Facility Building (Retirement Home/Aged care – 394m^2)

This model building is a single-storey building on a flat site and includes 12 residential bedrooms with washbasins, separate sanitary facilities, dining and lounge, commercial kitchen and laundry, staff accommodation, and office. The building construction comprises of reinforced concrete slab, timber-framed walls and prefabricated timber-trussed roof, external cladding of fiber-cement with textured coating, aluminum external joinery, pre-finished steel roof, and plasterboard linings.

The building is expected to have occupancy of 12 patients (one patient per bedroom) and 8 staff based on number of bedrooms. The number of staff is the maximum expected number of staff at any time. As per the Compliance Document C/AS1[1], the building is classified as SC, FHC1. SC represents the occupancy purpose group for care institutions of the aged / people with disabilities and FHC is the fire hazard category.



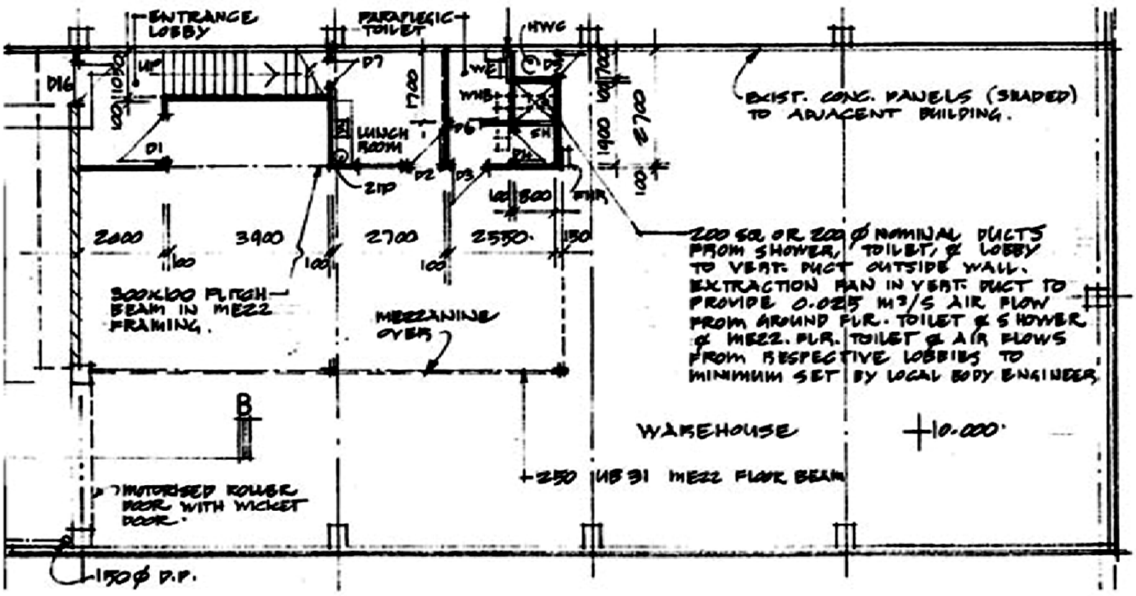
Extracted from the Department of Building & Housing Website
http://www.dbh.govt.nz/officials-estimated-building-costs#map1

Figure 7.2: Model Care Facility Building

7.2.3 Light Commercial (Office / warehouse – 414 m^2)

This model is a single-storey warehouse, with mezzanine on a flat site accommodating warehouse, office accommodation, reception and display area, staff lunchroom, kitchen, and toilet facilities. The building construction comprises of reinforced slab, reinforced concrete columns, tilt-up pre-cast concrete external walls, powder-coated external aluminum joinery, roller shutter doors, factory-painted steel roof, timber-framed internal partitions with painted plasterboard linings.

The building is expected to have occupancy of 20 persons in the office and 8 staff based in the warehouse. The occupant load is based on an occupant density of 0.1 persons/m^2 in the office area and 0.03 persons/m^2 in the warehouse. Common spaces like toilets, staffrooms corridors are not considered as it is expected to be occupied by persons counted elsewhere. As per the Compliance Document C/AS1[1], the building is classified as WL, FHC2. WL represents the occupancy purpose group for office/ warehouse and FHC is the fire hazard category. The fire hazard category of the warehouse can be higher if the storage height exceeds 3m.



Extracted from the Department of Building & Housing Website
http://www.dbh.govt.nz/bofficials-estimated-building-costs#map1

Figure 7.3: Model Light Commercial Building

7.2.4 Commercial – Retail (Offices/showrooms/retail – 896 m^2)

This model building is a single-storey building on a flat site with two retail units: one comprising retail area, two offices, kitchen, and toilet facilities; the other containing retail and toilet facilities. The building construction comprises of reinforced slab, driven timber piles, steel columns, tilt-up pre-cast concrete external walls, powder-coated external aluminum joinery, automatic sliding doors, factory-painted steel roof, timber-framed internal partitions with painted plasterboard linings, suspended ceiling to all but warehouse areas, and steel-framed fire wall between retail units.

The building is expected to have occupancy of 20 staff and 75 members of public based in the retail spaces. This has been based on an occupant density of 0.2 persons/m^2 in the retail areas and 0.1 persons/m^2 in the office areas. Common spaces like toilets, staffrooms corridors are not considered as it is expected to be occupied by persons counted elsewhere. As per the Compliance Document C/AS 1[1], the building is classified as CM, FHC2/4. WL represents the occupancy purpose group for office/ warehouse and FHC is the fire hazard category. The fire hazard category is higher (FHC4) if the storage height exceeds 3m.

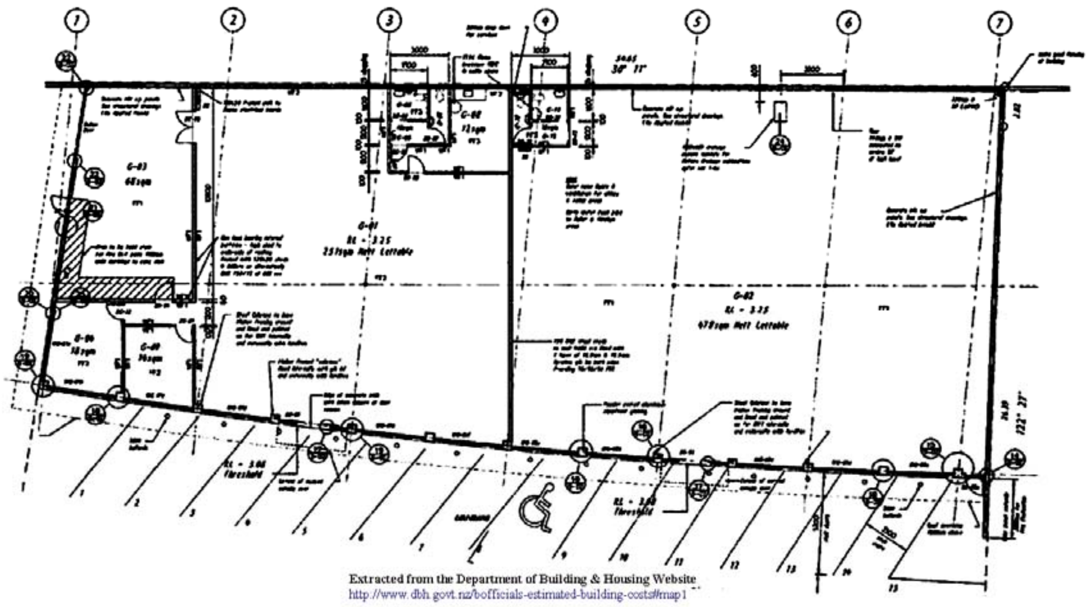


Figure 7.4: Commercial – Retail Building

7.3 Fire Initiating Event Likelihood

7.3.1 Rutstein - 1979

Rutstein[38], presented a model for calculating the probability of fire starting. He states that the fire hazard in a building consists of 3 components. These component are probability of fire occurring, the amount of fire damage, which might occur if a fire starts in the building and the possible financial losses resulting from the fire.

Rutstein[38] claims that the probability of fire occurring can be estimated by relating the number of fires which occur each year to the number of buildings at risk. The probability of a fire in a building is a function of the floor area and is expressed as:

$$P(A) = a\,A^b$$

Where A is the total floor area (m^2) of the building and a and b are constants for buildings of different occupancies. The values of a and b are given in table 7.1 below.

Occupancy	a	b
Industrial buildings		
Food, drink and tobacco	0.0011	0.60
Chemicals and allied	0.0069	0.46
Mechanical engineering and other metal goods	0.00086	0.56
Electrical engineering	0.0061	0.59
Vehicles	0.00012	0.86
Textiles	0.0075	0.35
Timber, furniture	0.00037	0.77
Paper, printing and publishing	0.000069	0.91
Other manufacturing	0.0084	0.41
All manufacturing industry	0.0017	0.53
Other occupancies		
Storage	0.00067	0.5
Shops	0.000066	1.0
Offices	0.000059	0.9
Hotels, etc	0.00008	1.0
Hospitals, etc	0.0007	0.75
Pubs, restaurants, etc*	0.00007	1.0
Schools	0.0002	0.75

Table 7.1: Ignition frequency constants

The values given in Table 7.1 are estimated from fires reported to the fire brigades. Using the above expression the estimated ignition frequency for the building models used for modelling we get the following estimates.

Care Facility Area = 394 m^2

a = 0.00007, b = 0.75 (Table 7.1)

P(A) = 0.00007 x $394^{0.75}$ = 0.00619

Ignition frequency per year per m^2 is

P(A)/A = 1.57 x 10^{-5} fires/year/m^2

Using similar calculations for commercial and retail occupancies using Rutstein's expression we get the following fire initiation frequencies.

Light commercial = 3.24 x 10^{-5} fires/year/m^2

Bulk retail = 6.6 x 10^{-5} fires/year/m^2

7.3.2 Tillander and Keski-Rahkonen - 2003

Tillander and Keski-Rahkonen[39] studied the ignition frequency of structural fires derived from Finnish statistics between 1996 - 1999. They showed ignition frequency varied with floor area. They proposed a model for determining ignition frequency of buildings with floor area between 100 and 20,000 m^2. Figure 7.5 shows data for different types of buildings. The ignition frequency model has the following form where f''_m is the ignition frequency (fires per m^2

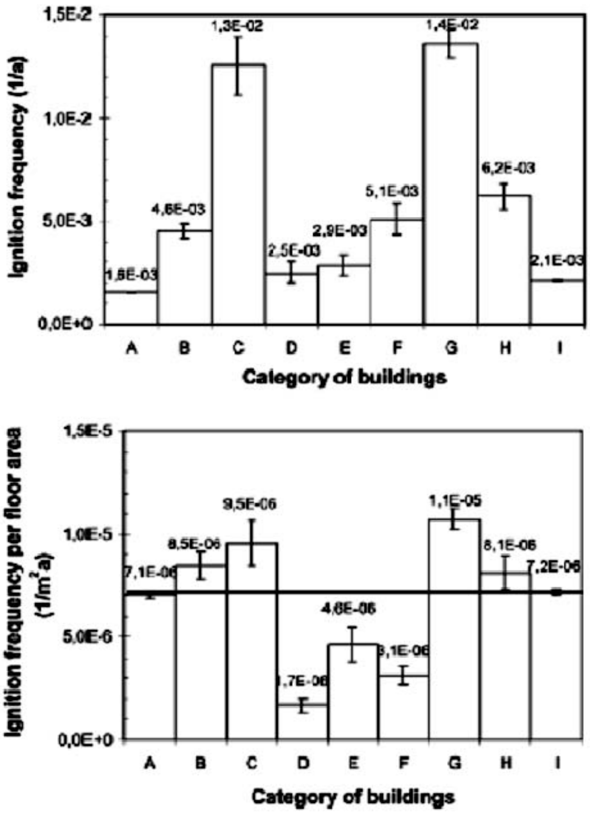
per annum) and c_1, c_2, r and s are constants fitted from the data (Table 7.2). A is the floor area.

$$f''_m = c_1 A^r + c_2 A^s$$

Coefficient	Residential	Non-residential
c_1	2.7	0.025
r	−3	−1.5
c_2	1E–5	1.3E–5
s	−0.15	−0.15

Table 7.2: Ignition frequency coefficients

Note that ignition is taken to mean a fire to which the public fire department is called.



A – Residential Buildings; B – Shop, accommodation, restaurants; C – Institutional buildings; D – Office buildings; E – Assembly buildings; F – Educational buildings; G – Industrial buildings; H – Warehouses; I – Mean of all buildings **[Extracted from Tillander 2003]**

Figure 7.5: Mean of Ignition Frequency and ignition frequency per floor area

The estimated ignition frequency is as follows:

Residential buildings (A) = 7.1×10^{-6} fires/year/m^2

Care facility buildings (C) = 9.5×10^{-6} fires/year/m^2

Commercial buildings (D) = 1.7×10^{-6} fires/year/m^2

Retail buildings (B) = 8.5×10^{-6} fires/year/m^2

7.3.3 Statistical Determination of ignition frequency

Sandberg[41] determined the ignition frequency in different buildings categories in Sweden based on data from the fire departments in Stockholm, Gothenburg and Malmö for the years 2000 to 2002 inclusive as shown in figure 7.6.

Key	Major group	Number of premises	No of fires	Floor area [10^6 m^2]	Average ignition frequency [1/y m^2]
A	Hotels and restaurants	5 463 ± 253	200	6.5 ± 0.3	$3.1 \cdot 10^{-5}$
B	Offices	16 200 ± 454	123	30.7 ± 0.9	$4.0 \cdot 10^{-6}$
C	Stores and warehouses	11 065 ± 578	227	14.0 ± 0.6	$1.6 \cdot 10^{-5}$
D	Buildings for institutional care	5 884 ± 332	575	18.4 ± 1.0	$3.1 \cdot 10^{-5}$
E	Educational buildings	13 053 ± 247	422	36.2 ± 1.2	$1.2 \cdot 10^{-5}$
F	Churches/correspondin g	5 505 ± 324	20	3.6 ± 0.5	$5.6 \cdot 10^{-6}$
G	Theatres, cinemas and other assembly buildings	11 715 ± 637	52	6.0 ± 0.7	$8.7 \cdot 10^{-6}$
H	Buildings for sport activity	3 806 ± 207	59	7.0 ± 0.8	$8.4 \cdot 10^{-6}$
I	Industrial buildings	41 335*	1274	112.0**	$1.1 \cdot 10^{-5}$

*Table 6.1. Number of premises and fires and the combined floor area in different building categories the year 2002. *The number of industrial premises the year 2003. **The floor area of industrial buildings is for the year 2003.*

Extracted from Sandberg(2004)

Figure 7.6: Ignition Frequency per floor area of different types of occupancies

The average ignition frequency is shown as the following for…

Offices	4.0×10^{-6} per m^2 per annum;
Stores and warehouses	1.6×10^{-5} per m^2 per annum;
Care institutions	3.1×10^{-5} per m^2 per annum;
Assembly buildings	8.7×10^{-5} per m^2 per annum.

7.3.4 New Zealand Fire Service Statistics

SFPE (NZ Chapter) [42] published data on the ignition frequency of fires in New Zealand based on statistics provided by the New Zealand Fire Service. The statistics were between 1 Jul 03 - 30 Jun 04. The data extracted was categorised into occupancies that are nearest to the descriptions of the C/AS1[1]. The following figure is an extract from that article.

Data extracted from Statistics 1 Jul 03 to 30 Jun 04 provided by NZ Fire Service

FS Code no	General Property Use	No. of fires	Area flamed m^2	Area smoked m^2	Total area of bldg m^2	No. of fire appliances	Avge no. of fire appliances	Area flamed per appliance m^2	No. Ignitions per million sq. metres of bldg
21/22	Construction	35	3,134	8,504	54,698	171	5	18	64
31	Single houses	1657	53,127	93,642	248,720	4580	3	12	666
32	Flats, Apartments, Home units	260	4,787	12,189	78,666	721	3	7	331
33/34	Boarding Houses, Hotels, Motels	26	211	2,225	123,918	91	4	2	21
39	Residential	32	984	1053	10573	84	3	6	303
41	Restaurants, Pubs, Taverns	61	1,717	4,818	42,816	287	5	18	142
42	Shops, Malls, Supermarkets	92	5,389	9,522	114,141	294	3	18	81
43	Service, Repair, Drycleaners, Mech workshop	27	1,481	1,903	8,666	114	4	13	312
44/52	Offices, Banks, Doctors, Dentists	36	565	6,322	94,309	198	6	3	38
45	Industrial, Manufacturing	126	17,200	23,930	419,510	596	5	29	30
46	Storage, Warehousing	53	10,712	12,853	34,147	207	4	52	155
47/48/59	Schools, Universities	104	1,523	6,858	86,362	316	3	5	120
49	Commercial (not classified above)	40	1,791	7,307	34,817	151	4	12	115
51	Hospitals, Rest homes	26	317	938	25,764	79	3	4	101
53	Prisons	3	45	43	12,250	8	3	6	24
61/62	Recreational, Stadiums, Theatres	42	1,795	1,733	20,853	125	3	14	201
63 to 69	Sports clubs, Churches, Halls	62	5,022	6,951	34,853	266	4	19	178

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Figure 7.7: Ignition data of New Zealand

The general property use is representative of the occupancy types specified in C/AS1. The estimated ignition frequencies from the above statistics are:

Residential - 3.303 x 10^{-3} to 6.662 x 10^{-3} fires /m^2/year *[FS code – 31, 32, 39]*

Care Facility - 1.01 x 10^{-3} fires /m^2/year *[FS code – 51]*

Commercial - 1.148 x 10^{-3} to 3.817 x 10^{-4} fires /m^2/year *[FS code – 43, 44/52, 49, 46]*

Retail - 1.424 x 10^{-3} to 8.060 x10^{-4} fires /m^2/year *[FS code – 41, 42]*

7.3.5 Comparing ignition data

Ignition data from different literature review has been compare in Table 7.3 below.

	Rutstein fires/yr/m^2	Tillander fires/yr/m^2	Sandberg fires/yr/m^2	NZFS fires/yr/m^2
Residential		7.1×10^{-6}		3.3×10^{-3} to 6.6×10^{-3}
Care Facility	1.57×10^{-5}	9.5×10^{-6}	3.1×10^{-5}	1.01×10^{-3}
Light Commercial	3.24×10^{-5}	1.7×10^{-6}	4.0×10^{-6} (offices)	1.1×10^{-3} to 3.8×10^{-4}
Bulk Retail	6.6×10^{-5}	8.5×10^{-6}	1.6×10^{-5} (stores/warehouse)	1.4×10^{-3} to 8.0×10^{-4}

Table 7.3: Ignition data comparison

This research project has used the New Zealand Fire Service (NZFS) ignition data for the purpose of modelling. The reason for selecting the NZFS data is because it represents actual fire ignitions in New Zealand as well as that the NZFS data shows a higher ignition frequency rate compared to the overseas data.

7.4 Fire Protection System Performance Probability

The probabilities used in the model event trees are derived from a variety of sources. It should be noted that most of the available probability data are based on fire incidents within a range of building types and are generally for ordinary fire loads. In general there is little available data relating to the effectiveness of fire prevention measures for different severities of fire hazard. Thus there is much uncertainty in the derivation of the model probabilities.

Houlding and Rew[43] in their assessment of benefits of fire compartmentation in chemical warehouses compiled probabilities derived from historical data. The fire hazards of the fuels considered in their model are characterised with respect to Comité Européen des Assurances (CEA) classification system for materials based on their properties of combustibility and explosibility.

Ref.	Material	Description	Fire growth rate	α (kJ/s^3)	Fire load
1	n-heptane	Highly flammable liquid	Ultra fast	0.188	High
2	Acetic acid	Flammable liquid	Fast	0.047	High
3	Aniline	Combustible liquid	Medium	0.012	High
4	Lead oxide	Metal compound	Medium	0.012	Low
5	Nitric acid	Strong oxidising agent	Fast	0.047	Low

Table 7.4: Fire Growth rate and relative fire loads

7.4.1 Detection

A study done by Bukowski[44], using literature review and analysis of available operational reliability data and performance reliability data estimated the following probabilities of detection system in Table 7.5.

BS DD240[45] provides probabilities for fire detection systems failing to operate based on work published in 1973 by the Fire Research Station. Their estimates are shown in Table 7.6.

Guymer and Parry[46] provide point estimate unavailability per demand for fire protection features based on data collected from US nuclear power plants in the 1970's and 1980's. They are given as operational reliabilities in Table 7.7.

Detector type	Occupancy / fire type	Operational reliability
Smoke detector	Commercial - general	0.72[1]
	Commercial – storage	0.68[2]
	Commercial – industry/manufacturing	0.80[2]
	Institutional – general	0.84[1]
Heat	Smoldering fire	0[3]
	Flaming fire	0.89[3]
Smoke	Smoldering fire	0.86[3]
	Flaming fire	0.90[3]
Beam smoke	SMOLDERING FIRE	0.86[3]
	Flaming fire	0.88[3]
Aspirated smoke	Smoldering fire	0.86[3]

1. **Derived from ten years (1983-1992) of NFPA Data provided by J.R. Hall[29]**
2. **Taken directly from J.R. Hall's paper[29]**
3. **Taken from Warrington DELPHI study [27]**

Table 7.5: Estimates of detection system operational reliability by Bukowski

Detector type	Operational reliability
Heat and smoke	0.90
Flame	0.76

Table 7.6: Estimates of detection system operational reliability by BS DD240

Detector type	Operational reliability
Heat	0.91
Smoke	0.87
Flame	0.76

Table 7.7: Estimates of detection system operational reliability by Guymer and Parry

Holding and Rew[43] further summarised the detection probabilities for manual detection alone and a combination of manual and automatic fire detection (AFD) in their models. Both manual and AFD are assumed to operate independently. They calculated the probability of detection as follows:

$$P_D = 1 - (1 - P_{AFD})(1-P_M)$$

Where:

P_D - probability of detection

P_M - probability of manual detection

P_{AFD} - probability of automatic fire detection

Detection type	Fuel Type				
	1	2	3	4	5
Manual alone	0.10	0.20	0.30	0.10	.20
AFD or flame detection alone	0.80	0.80	0.80	0.80	0.80
Manual and AFD	0.82	0.84	0.86	0.82	0.84

Table 7.8: Probability of Fire Detection Success by Houlding and Rew

The fuel type is defined in Table 7.4.

7.4.2 Automatic Fire Suppression

Probabilities for a fire being controlled or extinguished by automatic suppression are required. The probabilities are required for early suppression of a fire such that the damage occurs only to the area where the fire originates.

Bukowski[44] provided a review of estimates for the operational reliability of sprinkler systems ranging from 87.6% to 99.5%

The results of a DELPHI exercise by Warrington Fire Research[27] quoted operational reliabilities in the range of 95% with 64% of fires considered to be controlled by sprinklers.

BS DD240[45] provides probabilities for suppression systems failing to operate as designed and the values are assumed to be applicable to all building types and occupations. These are given as operational reliabilities in Table 7.9.

Suppression Type	Operational Reliability
Sprinkler	0.95
Gaseous	0.94

Table 7.9: Estimates of suppression system operational reliability by BS DD240

Guymer and Parry[46] provide point estimate unavailability per demand for fire protection features based on data collected from US nuclear power plants in the 1970's and 1980's. They are given as operational reliabilities in Table 7.10

Suppression Type	Operational Reliability
Halon	0.94
Carbon dioxide	0.96

Table 7.10: Estimates of suppression system reliability by Guymer and Parry

Houlding and Rew[43] further assessed successful control of fires based on liquid flows between compartments, oxidiser fires not being able to be extinguished by stopping oxygen supply and explosion risk. They used the following probabilities in their model. The fuel type is defined in Table 7.4.

Suppression type	Fuel Type				
	1	2	3	4	5
Water sprinklers	0.60	0.70	0.80	0.90	0.85
Foam/water sprinklers	0.80	0.90	0.95	0.95	0.90
Gaseous	0.80	0.90	0.95	0.20[1]	0.10[1]

[1] gaseous systems not effective with oxidisers

Table 7.11: Estimates of suppression system reliability by Houlding and Rew

7.4.3 Manual Fire-Fighting

Probabilities are required for a fire being extinguished or controlled by manual fire fighting noting that it is assumed that manual fire-fighting is only effective in the early stages of a fire. Thus manual fire-fighting probability depends when a fire has been detected by Automatic Fire Detection (AFD) or by on-site personnel (Manual).

Whether or not an AFD is installed, a fire will eventually be detected by people, whether onsite or offsite (people outside the facility). For manual fire-fighting we are concerned only with early detection and thus detection by personnel within the vicinity. Houlding and Rew[43] stated that 1000kW is the upper limit for fires amenable to first-aid fire fighting. For the purpose of this model a notional fire size of 1000 kW is taken as the upper limit for first-aid fire-fighting (equivalent to 5 minutes for medium fire growth). The model does not account for manual detection beyond this fire size and success probabilities for manual fire fighting relate to fires of this size or smaller.

Melinek [48] suggests that 25% of the fires in non-domestic premises are fought before the arrival of the fire service are out on arrival. Matthews ET. al.[31] suggests a success rate of 75% for emergency teams putting out ordinary combustible fires. Guymer and Parry[46] reference work undertaken for the nuclear industry looks at generic fire hazards. They have assumed that manual suppression would need to be undertaken within 3 minutes of detection if the fire was not to grow to an unmanageable size for which they gave a 0.4 probability of the fire being extinguished.

Houlden and Rew[43] summarised probabilities of manual suppression (Table 7.12) based on the fact that there is some level of manning at all times. These personnel would either be those detecting a fire or those responding to an AFD. The fuel type is defined in Table 7.4.

	Fuel Type				
	1	2	3	4	5
Manual suppression	0.1	0.2	0.4	0.4	0.2

Table 7.12: Probabilities of success of manual suppression by Houlding and Rew

Manual fire fighting response success probability has also been assessed on the data collected by the UK and EUROFEU Fire Trades Association in 2002[10] which indicates that 85% of fires was successfully contained / extinguished by the use of extinguishers and for about 75% of the cases the Fire Service did not attend. The surveys done in New Zealand also indicate a success probability between 90 – 94% of a fire extinguished by portable extinguishers. The Swedish Fire Service review[11] indicates that fire extinguishers were able to put out 61% of fires. Therefore for this research it is reasonable to have a probability range of 0.8 (maximum value) and 0.2 (minimum value).

7.4.4 Fire Compartmentation Success

There is very little comprehensive data in the literature regarding the performance success probabilities of fire separations. The results of a Delphi study done by Warrington in 1996[49] are often quoted along with Bukowski et. al.[44]

Wall type	Operational reliability[1]
Masonry construction	0.81
Gypsum partition	0.69

1. Probability that wall will have no penetrations which are fixed open

Table 7.13: Estimates of fire compartmentation operational reliability by Bukowski

British Standard BS DD240[45] provided some probabilities of passive fire protection failing to operate as designed (stated to be taken from an ASTM study)

Protection feature	**Operational reliability**
Fire door	0.70
Self-closing door to protected stairway	0.90

Table 7.14: Estimates of compartment penetration reliability by BS DD240

Houlding and Rew[43] adopted values for the probability of success of wall constructions for a range of fires. The values of plasterboard walls reflect their assertion that they would not perform well in conditions which were representative of hydrocarbon fires.

Wall type	Fuel Type				
	1	2	3	4	5
Concrete	0.95	0.95	0.95	0.95	0.95
Masonry	0.70	0.75	0.80	0.80	0.75
Plasterboard	0.40	0.50	0.60	0.70	0.65

Table 7.15: Probabilities of success of wall construction by Houlding and Rew

7.5 Fire Exposure Profile

An important part of Event Tree Analysis (ETA) is establishing time-line factors. This is usually evaluated using fire dynamics calculations and fire models. The time-line factors used for this assessment are based on the following table. These time-line factors are similar to the examples used by Barry[33] for risk analysis.

Figure 7.8 shows an uncontrolled fire exposure profile and been based on estimated temperatures as the fire reaches growth, peak HRR and fire spread stages and the probable consequences. The fire exposure profile is similar to examples used by Barry[33] for risk analysis.

The fire exposure profile assumes that the manual intervention using portable extinguishers is achieved within 3 – 5 minutes of the fire initiation and growth where the temperature range is between 30 – 40 deg C. Sprinkler activation and suppression is achieved within 5 – 10 minutes of the fire growth. Sprinkler activation is assumed to happen if either manual intervention is unsuccessful or manual intervention is not performed. Between 10 – 30 minutes, the fire separations are expected to perform providing a barrier for fire spread.

Target	Time -Limits	Actions
People evacuation	1 - 3 minutes	Detection Time + Alarm Notification Time + Evacuation Time < 3 minutes.
Manual suppression	3 – 5 minutes	Detection of Fire + Use of portable Extinguisher Time < 5 minutes.
Equipment activation	5-10 minutes	Detection Time + BMS (Building Management System) + Automatic Fire Suppression < 10 minutes
Structural integrity (1)	10-30 minutes	Fire Brigade/Fire Department Notification Time + Response Time + Manual suppression / Extinguishment Time < 30 minutes
Secondary Effects (2)	30-60 minutes	Compartment Fire Resistance Integrity Maintained for 60 minutes to accommodate delayed Fire Dept. response

(1) i.e. start of structural damage in immediate area of fire origin

(2) i.e. fire propagation beyond compartment of fire origin

Table 7.16: Time-Line Parameters

Figure 7.8 depicts the growth of a fire and its spread to secondary fuel sources. The design fire is based on a medium fire. Design fires are further discussed in section 7.6. The time line is as per table 7.15, where Zone B indicates people evacuation, Zone C indicates that successful manual intervention would result in suppression of the fire at an early stage (Curve C), Zone D and E is the region of activation of sprinkler and suppression (Curve B), Zone F indicates fire barrier integrity.

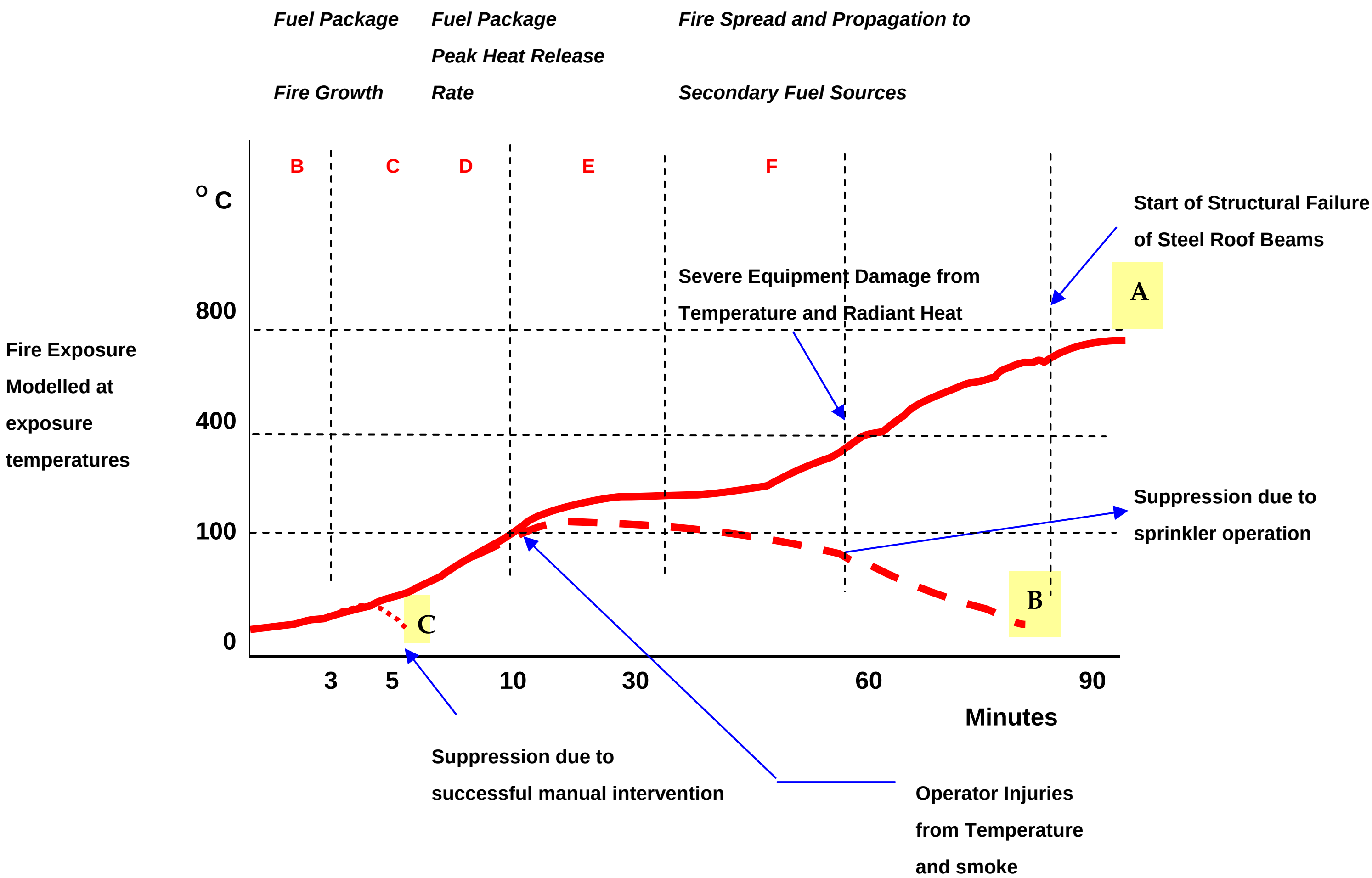


Figure 7.8: Uncontrolled Fire Exposure Profile

7.6 Design Fires

A fire hazard analysis relies on the assumptions of fire growth. The time scale for the fire depends on the selection of the design fire and this time scale further determines time for fire spread and time available for escape etc as discussed in section 7.5. Therefore there is the need to arrive at a plausible design fire has been the objective of research work for years. Section 7.5 defines the time lines for an uncontrolled growth generic fire. The most frequently suggested design fire is the t^2 fire where the heat release rate is described by the following equation:

$$\dot{Q} = \dot{Q}_0 \left(\frac{t}{t_g} \right)^2$$

Where Q_0 is normally chosen to 1MW and t_g is the growth rate or the time to reach 1MW. The recommended values for t_g are 600, 300, 150 and 75 seconds for slow, medium, fast and ultra fast fires respectively.

Design fire scenario	Category
Upholstered furniture and stacked furniture near combustible linings	*Ultra fast*
Light- weight furnishings	*Ultra fast*
Packing material in rubbish pile	*Ultra fast*
Non- fire retarded plastic foam storage	*Ultra fast*
Cardboard or plastic boxes in vertical storage arrangement	*Ultra fast*
Office furniture- horizontally distributed	*Medium*
Displays and padded work- station partitioning	*Fast*
Bedding	*Fast*
Floor coverings	*Slow*
Shop counters	*Medium*

Table 7.17: Design fires as given in ISO/CD 13388

Fire growth curves are shown in figure 7.9. The generic fire discussed in section 7.5 is based on the medium growth fire.

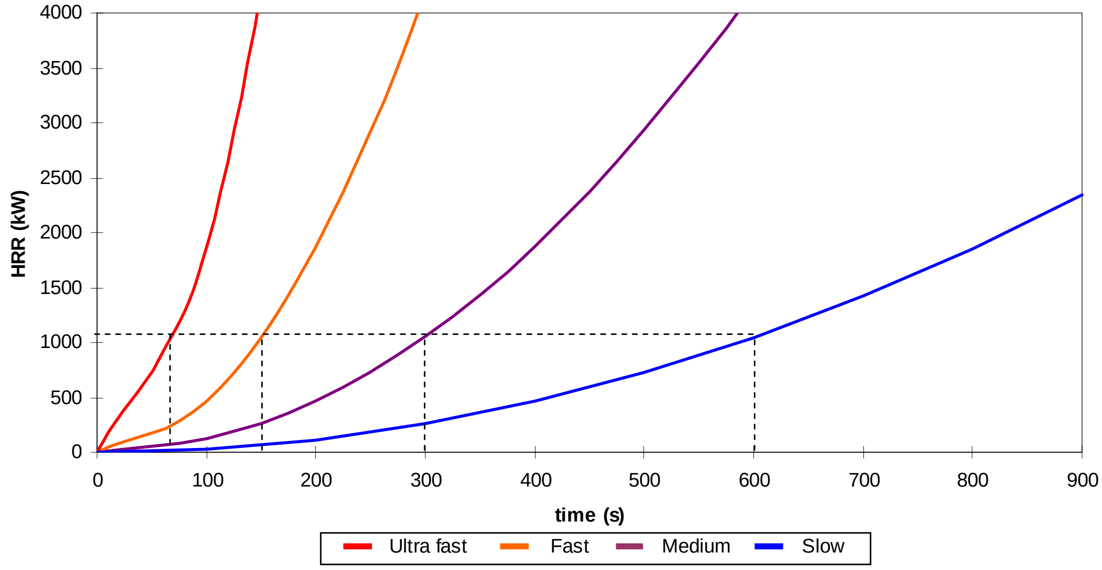


Figure 7.9: t^2 Fire Exposure Profile

Nordic regulators[68] published a document that assigns a design fire as a function of type of occupancy. This was inside a committee called NKB, "Nordic Committee on Building Regulations". NKB gives a selection of design fires as a function of the type of occupancy.

Category of use	α (W/s^2)
A (dwellings)	12
B (hotel)	50
C (shops, public spaces)	190
D (schools, offices)	50
E (industry of large fire hazard)	Not applicable

Table 7.18: Design fires as given in NKB

The design fire is expressed as:

$$\dot{Q} = \gamma_q \alpha t^2$$

Where:

Q	HRR (kW)
α	from table 8.15
t	time (sec)
γ_q	partial coefficient

There are no recommendations on how to use the partial coefficient. The expression was expected to give the same result as the expression $Q=Q_o\ (t/t_g)^2$.

There have been actual fire tests done by various research labs and these tests are the closest to a more realistic design fire. Based on the type of occupancy models being considered, some of the fire test data from NIST[51] and the University of Canterbury Design Fires Database[52] have been plotted in figure 7.9 and 7.10.

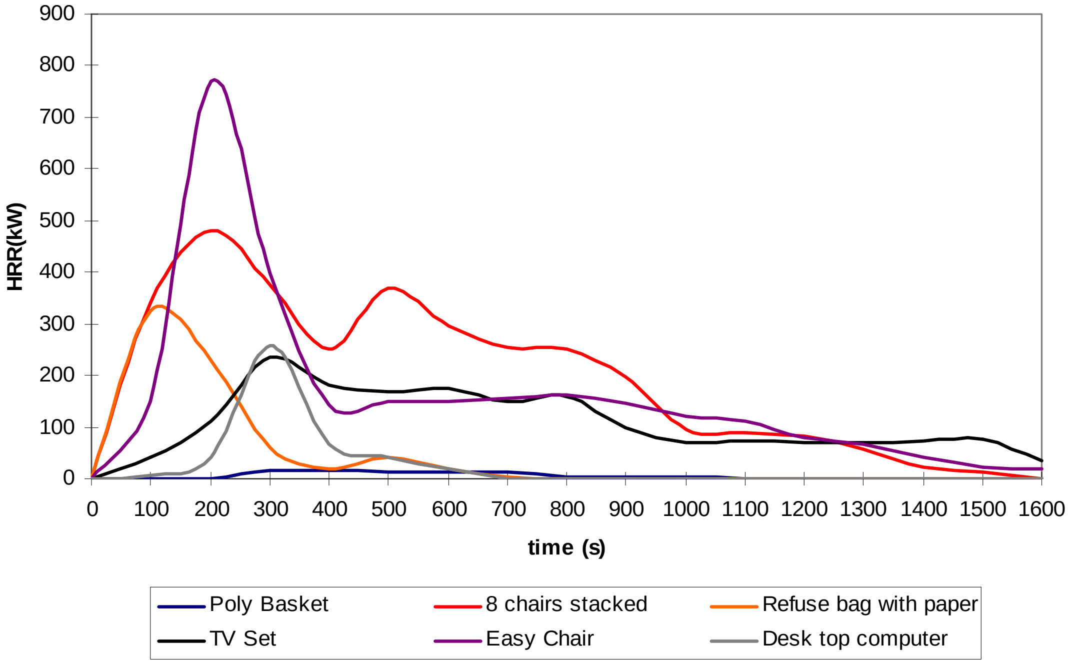


Figure 7.10: Fire Exposure Profile for low HRR

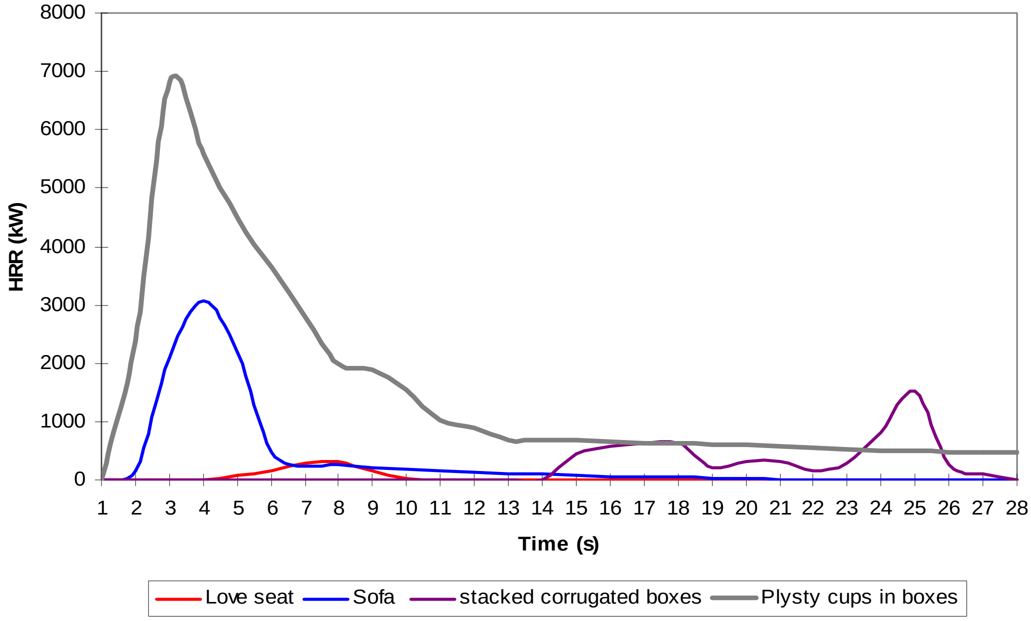


Figure 7.11: Fire Exposure Profile for high HRR

7.7 Cost Evaluation

Considering current minimum requirements for the model buildings based on current compliance documents (C/AS1, 2005[1]), the most likely fire protection systems to increase the level of protection would be automatic fire alarm systems, automatic sprinkler systems and /or additional fire compartmentation. The analysis looks at fire extinguishers being used at the initial stages of a fire to suppress or control it thereby reducing the losses in a fire. The purpose of this section is to gather information relevant to cost of including these systems in the model buildings.

7.7.1 Building Costs

The Department of Building and Housing (DBH)[36] provides building costs to assist Territorial Authorities to arrive at realistic estimated values while processing Building Consent applications. The DBH provides these figures by regions.

Building costs per square meter ($/m2) including GST as at Jan 2008

Region	Building type				
	House* 145 m²	House* 202 m²	Light commercial 414 m²	Commercial 896 m²	Retirement home 394 m²
1	1768	1493	1267	1305	2027
2	1695	1443	1210	1252	1964
3	1720	1459	1231	1273	1975
4	1737	1481	1234	1267	2011
5	1736	1471	1237	1287	2000
6	1686	1434	1204	1250	1957

Figure 7.12: Average Building Costs issued by DBH

The following costs are taken from the 2006 Rawlinsons New Zealand Construction Handbook[53].

Building Costs per Square Meter

House	$1450 to $1825
Retirement Home	$1638 to $2788
Light Commercial	$1135 to $1370
Commercial Retail	$1310 to $1500

Maltbys (2005)[37] estimates the fire protection cost (including hose reels and extinguishers) as a percentage of the total cost to be 0.6% for a light commercial building, 1.7% for bulk retail and 4.3% for retirement homes.

7.7.2 Fire Protection Systems

The following costs are taken from the Rawlinsons New Zealand Construction Handbook[53], Fire research report No. 1[54], Beca Cost Management[55], Spencer[56] and Andrews[57].

Fire protection Systems (with sprinklers but excluding pumps and tanks)

Residential Sprinklers	\$25 - \$35 / m^2
Rest Homes	\$35 - \$55 / m^2
Light Commercial	\$45 - \$55 / m^2
Bulk Retail	\$55 - \$65 / m^2
Annual Maintenance costs	\$635 - \$700 per annum

Detector and alarm systems

Residential (stand alone units)	\$15 - \$30 each (supermarket prices)
Fire Alarm panel	
Minor project	\$2,000 - \$3,500
Medium Project	\$3,000 - \$10,000
Thermal detectors and circuits	\$95 – \$100 each
Smoke detectors and circuits	\$180 - \$220 each
Fire bell and circuitry	\$90 – \$100 each
Variable cost	
for detectors sounders and call points	\$9 - \$11 /m^2
Annual Maintenance per building	\$700 (monthly testing and annual survey)
Fire Service Connection per annum	\$1000

Fire Extinguishers

Estimates were provided by fire protection companies during a fire extinguisher survey done between May – Jul 2008.

Average cost of extinguisher	\$170 - \$225 each
Average cost of installation per unit	\$20 - \$55
Average cost of maintenance per unit	\$8 - \$10 (Annual Maintenance)
Average cost of refilling per unit	\$51 – \$70
Average cost of training per person	\$34

NZS 4503:2005[8] gives the distribution requirements for portable fire extinguishers. For Class A fires NZS 4503 gives the minimum coverage area for the extinguishers of the lowest rating (2A) as 300m^2 for light hazard and 200m^2 for medium hazard. Residential, offices are considered as light hazard, care facilities and retail / storage are considered medium hazard based on hazard classification in NZS 4503[8]. Therefore it is estimated that the model buildings will require the following numbers of extinguishers.

Residential building (202m^2)	- 1 extinguisher
Care facility building (394m^2)	- 5 extinguishers
Light commercial (414m^2)	- 5 extinguishers
Bulk retail (896m^2)	- 8 extinguishers

The extinguisher count has taken into consideration accessibility and minimum distance requirements to the hazard. It can be assumed that extinguishers will require to be pressure tested, refilled and may require new signage etc every 5 years and the maintenance cost has factored this estimate.

As required by the Health and Safety in Workplace Act[24], employees are to be trained to use extinguishers. This requires a refresher course every 2 years and a retraining of new staff assuming an 21% turnover every year[62]. This equates to an average cost of training of approximately $17 per person per year over the lifetime of the building. Training costs do not apply to private residences.

Fire Separations (inter-tenancy walls)

1 hour rated, non-load bearing, plasterboard/timber	\$107 - \$109/m^2
2 hour rated, non-load bearing, plasterboard/timber	\$141 - \$164/m^2

7.8 NZBC Requirements for the Model Buildings

This section summarises the fire protection requirements given by the Acceptable Solutions C/AS1[1] for the New Zealand Building Code.

The relevant occupancy, occupant load and fire hazard category for the model buildings is given in table below. All buildings are considered to be single level in this study with a mezzanine in the light commercial building. The mezzanine is assumed to be a limited area intermediate floor thus does not require any smoke control as specified in C/AS1[1]. The bulk retail building is assumed to have one half of the occupancy to be a supermarket with storage greater than 3m with an inter-tenancy wall.

Building Type	Purpose Group	Occupant Load	Fire Hazard Category	Escape height
Residential	SH	5 persons	1	0m
Care Facility	SC	20 persons	1	0m
Light Commercial	WL	28 persons	2	2 floors
Bulk Retail	CM	95 persons	2/4	0m

Table 7.19: Occupancy classification and escape heights of model buildings

The fire protection requirements are taken for the calculated occupant load and the next higher occupant load category as per C/AS1 part 4[1].

Building Type	Occupant Load	F-Rating	Fire Safety Precaution						
			2f	3f	4	6	7	16	18c
Residential	5	F0							
Care Facility	20	F0					√	√	√
Light Commercial	<100	F60	√						√
	>100, <500	F60		√				√	√
Bulk Retail	<100	F0	√						√
	>100, <500	F0		√				√	√

Table 7.20: Fire Safety Precautions required for the Model Buildings

The descriptions of the fire safety precautions are enclosed in Appendix A.

7.9 Fire Loss Calculation

Business Economics Research Limited (BERL) carried out an economic assessment of industrial fires[58] in 2000. This assessment provided some cost estimates to impacts of fire. The findings were related to industrial buildings. This study uses the figures from the BERL findings interpolating it to the other occupancies and converting the year 2000 dollars to year 2007 dollars by 18%.

BERL analysis[58] was based on 1100 structure fires for the year 2000. The total estimated cost to the country was a total of $86 million. This total cost is broken down in the table below. The table also estimates the current cost per fire in 2007.

Cost area	Total cost Y2000	Estimated total cost per fire in Y2007 (x1.18/1100)
Business interruption	$8.0 m	$8,582
Other direct economic	$36.0m	$38,618
Fire Service	$23.0m	$24,673
Indirect economic	$8.5m	$9,118
Reduced consumption	$2.1m	$2,253
Social Costs	$8.5m	$9,118
Total	$86.1m	$92,362

Table 7.21: Estimated costs per fire

The above data does not include incidents that relate to non-commercial activities such as government, community, households, parking buildings etc.

Wade[59], had used a similar assumptions for estimating losses for industrial buildings and suggested that the uncertainty or likely distribution of the cost per unit area of the fire loss in unknown. Based on research done by Wade[59], it was decided to represent the cost parameters as normal distributions with the mean value taken as the estimated values and a standard deviation equal to 10% of the mean. The same has been used for this study.

Residential fires have different cost estimation in terms of property losses and fire service costs. Wade et. al.[60] estimated property losses in residential fires based on information from the insurance council and the presence or absence of smoke alarms in reported fire incidents. They suggested a weighted average value of $16,605 per fire incident. They also estimated an average cost of $5875 per residential fire as the Fire Service attendance costs. Similar to industrial buildings, the residential fire costs can also be represented as normal distributions with a standard deviation of 10%.

7.10 Event Tree Fire Risk Model of Fire Protection Systems in the Building

The event tree for the operation of fire safety systems in the building is shown in Figure 7.11 below. The probability of the successful operation of the systems is based on the discussion in section 7.4. The event tree analyses the success of fire safety systems provided in the building. The initiating fire likelihood is considered as per the discussions in section 7.11.5 further ahead. It is assumed that the automatic fire alarm activation is the first event which initiates evacuation and prompts the use of manual fire fighting response. Sprinkler activation is considered only after manual fire fighting response fails.

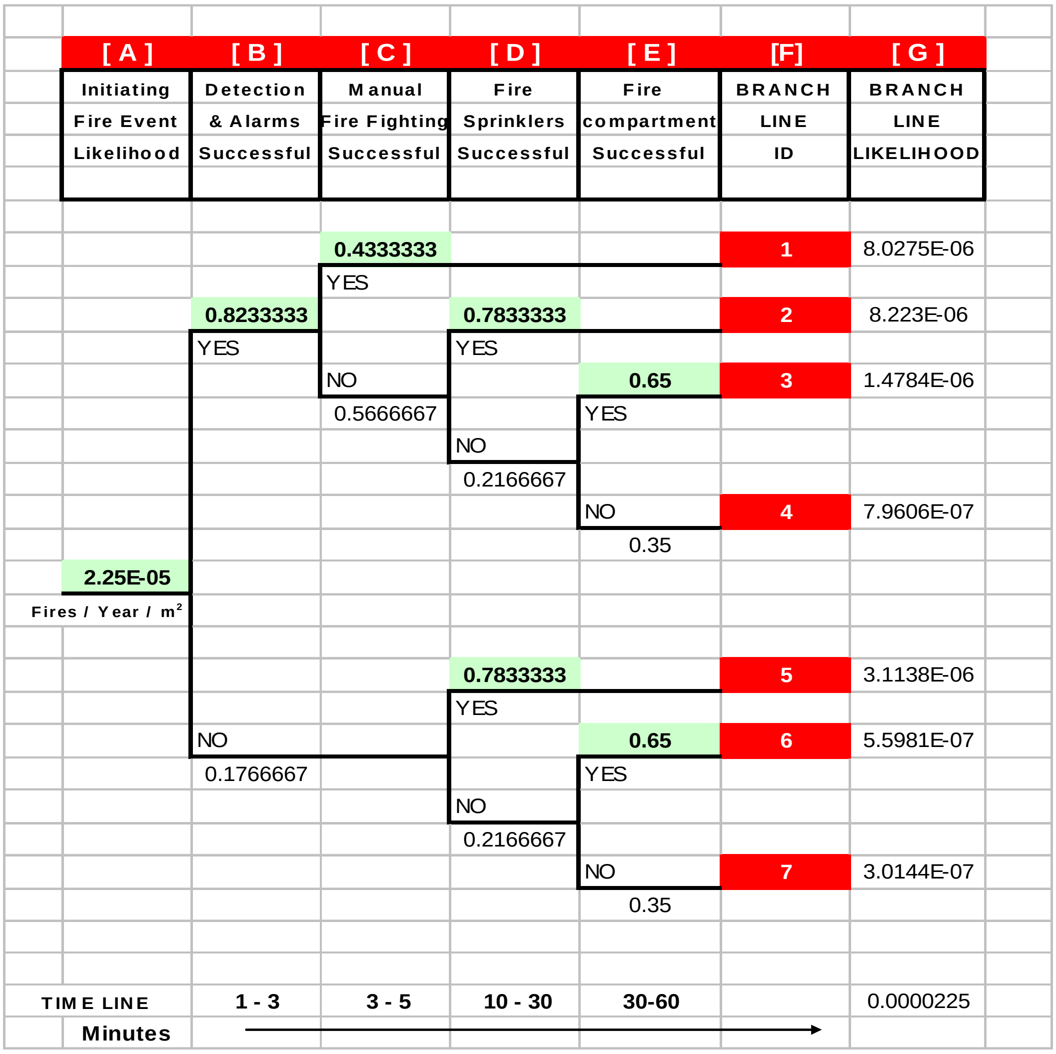


Figure 7.13: Event Tree for Risk Analysis

Each branch line represents a scenario outcome. For example branch line 1 indicates that fire occurs, the fire is successfully detected within 1-3 minutes, the fire is manually suppressed within 3 to 5 minutes. Therefore branch Line 1 probability = (A) x (B-1) x (C-1) = 8.0275 x 10^{-6}.

The branch line likelihood is then used for calculating the fire loss for the specific scenario of the model.

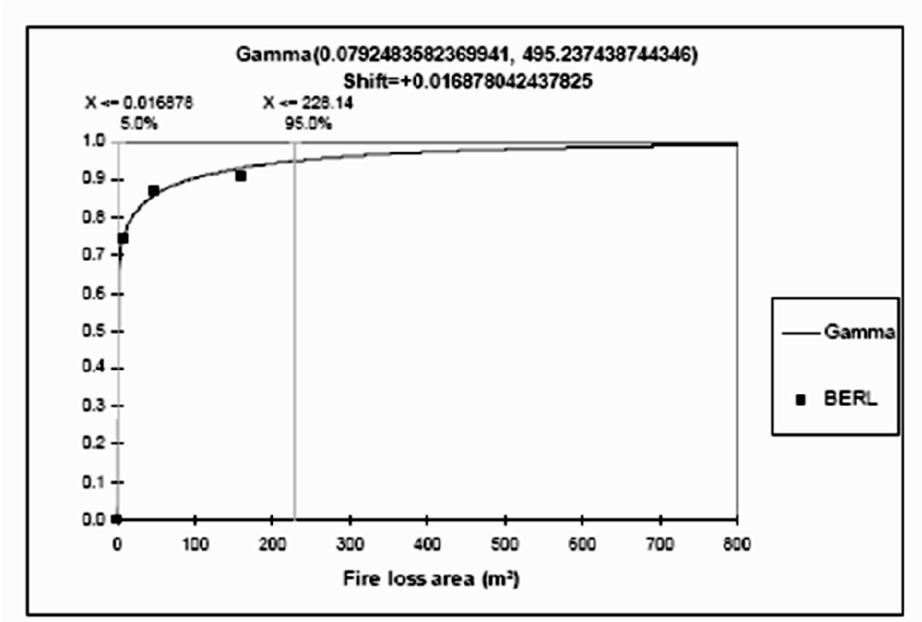
7.11 Model Inputs

This analysis uses the following cost scenarios for the building defined in section 7.2

7.11.1 Fire Loss Area for buildings with no protection

This situation is considered to most closely represent the current situation in New Zealand for residential buildings, and commercial buildings. 80 – 90% of rest homes / care facilities in New Zealand are provided with sprinkler systems as per Palmer et. al.[61]. The fire loss area (expressed in m^2 of floor area) is taken as the key measure of fire loss in the model.

Wade[59] estimated the fire loss area per fire to be $32m^2$. This was based on the BERL study[58] which analysed the composition of property damage for industrial buildings in New Zealand for the year 2000 using New Zealand Fire Service incident statistics. The composition of property damage from BERL data was put in a gamma distribution by Wade[59]with the fire loss area greater than 228 m^2 for 5% of the fires (95th percentile). It has also been truncated at the upper end so that the fire loss cannot be greater than the actual building floor area.



Extracted from Fire Research Report No. 1, Wade et. al., 2006

Figure 7.14: Cumulative distribution for fire loss area for an unprotected building

A comparison of percentage fire saves in 2006-07 and the BERL data is shown in the following table. The data in the table has been extracted from the New Zealand Fire Service – Incident Statistics and BERL Survey 2000 for industrial buildings.

Structure Fires

Data for 2006-07			BERL Data 2000				5 year average incidents (2002-07)			
Structure saved		% saved	Total incidents	% saved	Total area lost (m^2)	average area lost per fire (m^2)	residential	care facility	bulk retail	light commer
0-10%	522	18	101	9	16181	160	415	21	74	18
11-50%	308	11	42	4	6970	165	245	12	44	10
51 -90%	601	21	140	13	6552	47	478	24	85	20
91-100%	1391	49	817	74	5352	7	1107	56	197	47
Total	2822	100	1100	100	35055	32	2245	114	399	95

Table 7.22: Percent structure saved data

The above table show a large increase in percent property saved between BERL[58] and 2006-07 data for 0 – 90% of structure saved. This may be attributed to better fire protection systems, compartmentation and fire service intervention. Percent structure saved of 0 -10% may be considered as a complete burnout of the structure and therefore we assume that these buildings did not have any fire protection system and fire service intervention was minimal or not present. Percent structure saved of 11 – 50% can be considered to be attributed to successful compartmentation and fire service intervention.

For the purpose of this study the following probability inputs were used for buildings with no fire protection systems installed.

Fire not controlled – 0.18
Fire controlled by fire service intervention – 0.11

7.11.2 Fire Loss area for buildings with fire detection and manual suppression

Ramachandran[47] stated that an initial damage of 3m^2 is likely to occur before the heat generated in a fire is sufficient to activate a sprinkler system. Houlding and Rew[43] stated that 1000kW is the upper limit for fires amenable to first-aid fire fighting. In table 7.21 the BERL data indicates an average 7m^2 area lost per fire where 90-100% of the structure is saved. This will be assumed to be attributed to successful manual suppression. For the purpose of this study we have used the range of 1 – 3 m^2 as the area lost per fire.

Where buildings include fire detection and manual suppression the fire loss area is taken as a uniform distribution with a range of 1 – 3 m^2. Manual suppression can occur both earlier and later than sprinkler activation since depending on when human intervention occurs. For the purpose of this study we are assuming that the fire has been detected at an early stage via manual detection (humans) or by an automatic fire detection system and that manual suppression is effective.

Figure 7.15: Probability density function for fire loss area with manual suppression

7.11.3 Fire Loss area for sprinkler protected buildings

Wade[58] estimated the fire loss area per fire to be 20m^2. The typical maximum area of coverage of a fire sprinkler head is in the range of 6m^2 from NZS 4541.

Where buildings include an automatic fire sprinkler system, and where these are assumed effective, the fire loss area is assumed to be randomly sampled between 3 – 20m^2. Since the probability of occurrence is same for all values over the nominated range the uniform distribution is used to represent it. The assumed fire loss area is considered to be applicable to all types of building models considered.

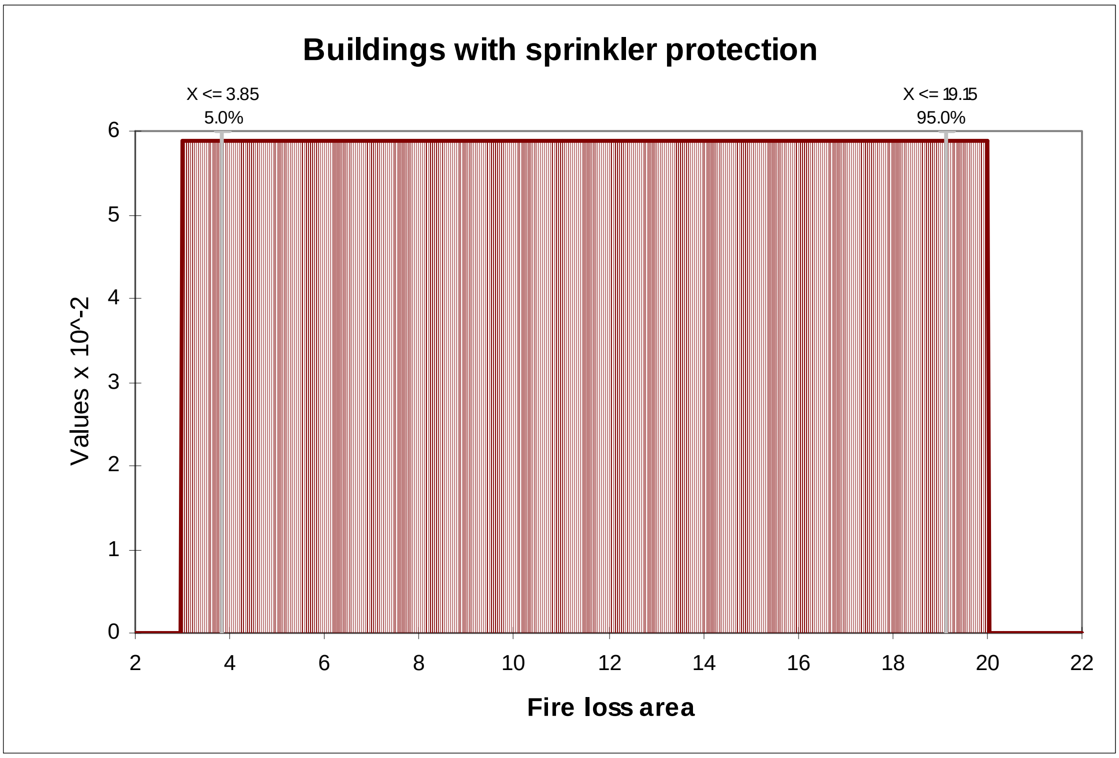


Figure 7.16: Probability density function for the fire loss area with sprinklers

7.11.4 Fire Loss area for buildings with fire compartmentation

Wade[59] stated that the probability distribution for the area of fire loss in a compartmented building is assumed to be the same for an unprotected building with the maximum fire loss not exceeding the nominated maximum fire cell area for each iteration. Wade considered an average of 39m^2 per fire. For this research we have used a single firecell area as maximum fire loss area for successful compartmentation in the event of a fire.

7.11.5 Fire Incident rate

Residential Buildings

Wade et. al.,[54] estimated that 0.0045 reported fires per year per household on an average during the period 1993 to 1997. This included structure and non structure fires. Analysis of New Zealand Fire Service statistics between 1986 to

1994 determined an average of 0.0041 reported fires per year per household for structure fires. Wade et. al.[60] further estimated an average fire incident rate per year per household. The incident statistics was limited to one and two family dwellings. Barnett[42] provided New Zealand Fire Service statistics for 2003-04 and suggested a fire incident rate between 0.0033 – 0.0066 fires per m^2

This research has used the PERT distribution to represent most of the input values to the risk model. Like the triangular distribution, the PERT distribution emphasizes the "most likely" value over the minimum and maximum estimates. However, unlike the triangular distribution the PERT distribution constructs a smooth curve which places progressively more emphasis on values around (near) the most likely value, in favor of values around the edges. In practice, this means that we "trust" the estimate for the most likely value, and we believe that even if it is not exactly accurate (as estimates seldom are), we have an expectation that the resulting value will be close to that estimate.

The fire incidence rate for residential buildings is represented using the maximum, most likely and minimum value as 0.0045, 0.0040 and 0.0033 respectively.

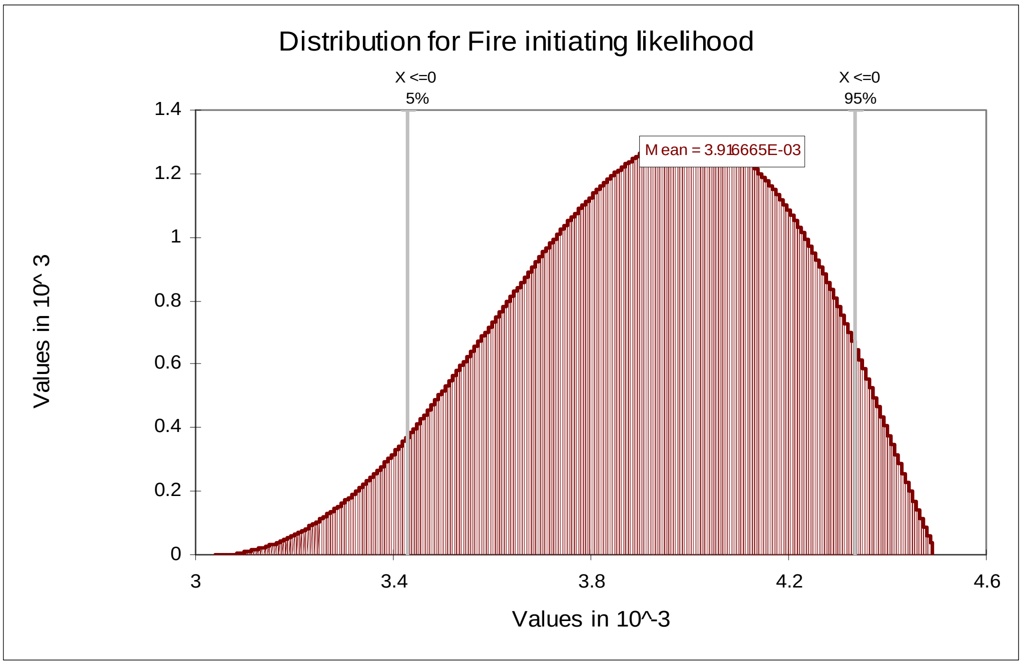


Figure 7.17: Probability density function for fire incidence rate - residential buildings

Care Facility, Commercial and Retail Buildings

Section 7.3 discussed ignition frequencies determined by research over the world and study done in New Zealand. The author has used a fire initiating frequency based on Barnett[42] that captures fire incidents in the country. The ignition frequency used for simulation for the building models used is

Care Facility - 1.01 x 10^{-3} fires /m^2/year

Commercial - 3.01 x 10^{-3} fires /m^2/year

Retail - 1.424 x 10^{-3} fires /m^2/year

7.11.6 Fire Protection System Probability of Success

The probability of the fire protection systems being effective (or not) are represented by pert distributions since detailed data is difficult to source. The pert distribution are a special form of beta distribution using minimum value, maximum value and most likely value that have been identified from various literature review as detailed in section 7.4.

The probability of detection success is described by pert distributions the maximum, most likely and minimum value as 0.9, 0.84 and 0.68 respectively. These probabilities are based on figures given by Bukowski[44] and Houlding and Rew[43]

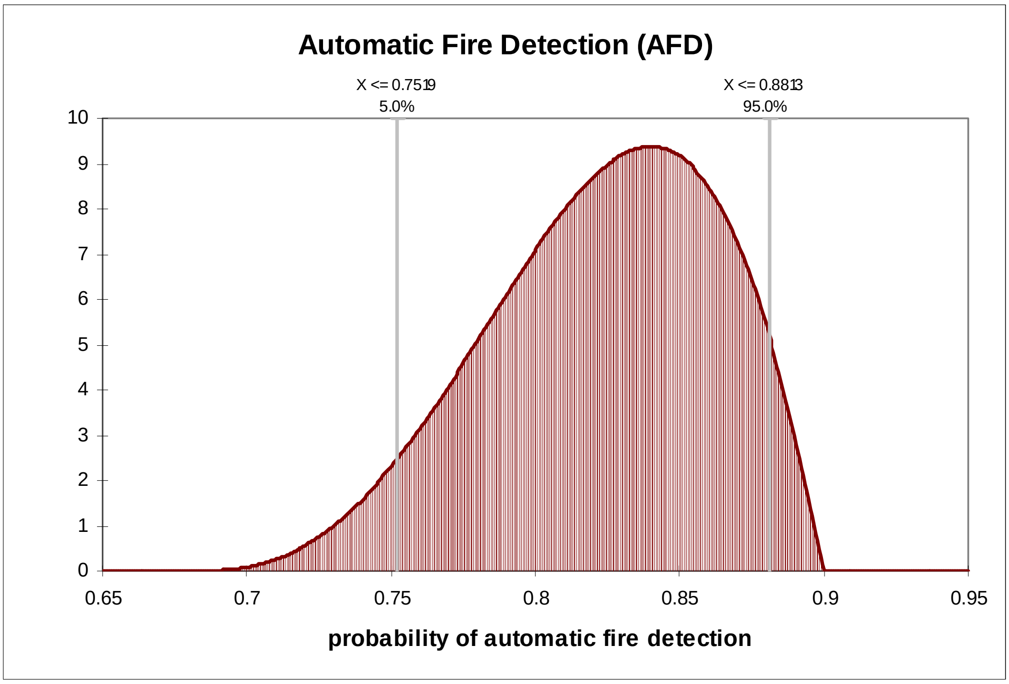


Figure 7.18: Probability density function for fire detection success

The probability of manual suppression success is described by pert distributions the maximum, most likely and minimum value as 0.8, 0.4 and 0.2 respectively. These probabilities are based on figures given by Houlding and Rew[43] and the UK Fire Extinguisher Survey[10]. (Refer figure 7.19)

The probability of sprinkler suppression success is described by pert distributions the maximum, most likely and minimum value as 0.9, 0.8 and 0.6

respectively. These probabilities are based on figures given by Houlding and Rew[43] and BS DD240[45]. (Refer figure 7.20)

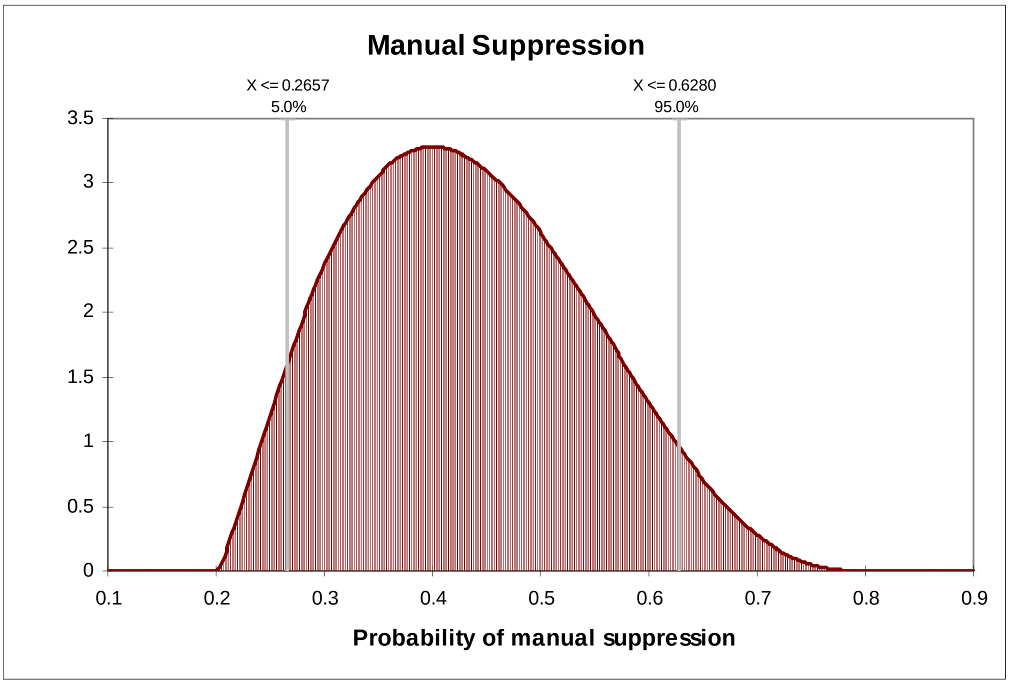


Figure 7.19: Probability density function for manual suppression success

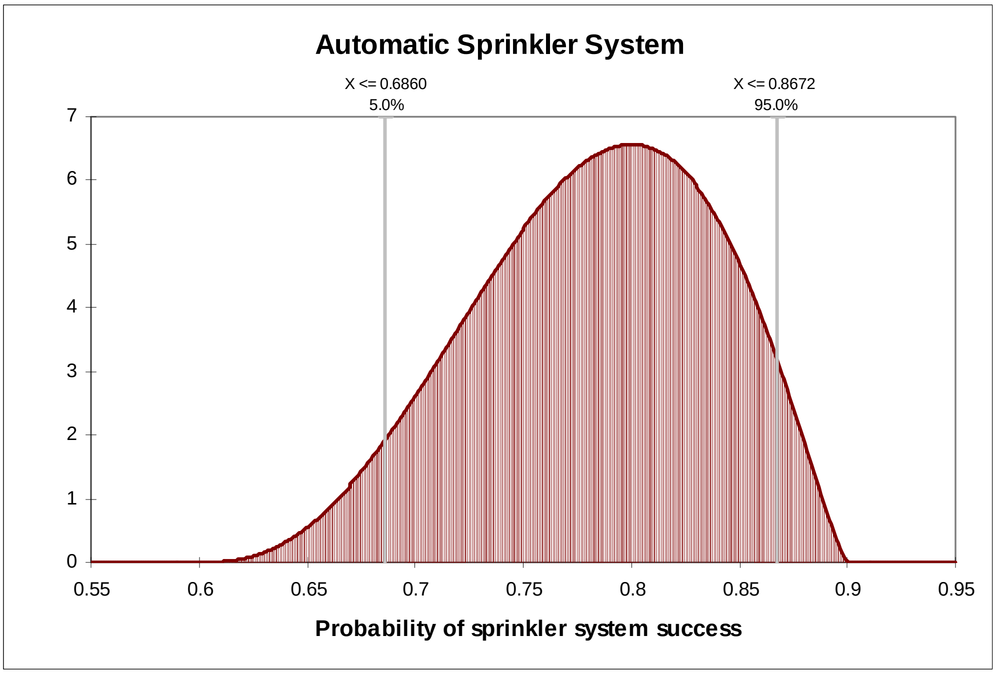


Figure 7.20: Probability density function for sprinkler suppression success

The probability of fire compartmentation success is defined by the success of fire walls and penetrations. This is described by pert distributions the maximum, most likely and minimum value as 0.9, 0.65 and 0.4 respectively. These probabilities are based on figures given by Houlding and Rew[43].

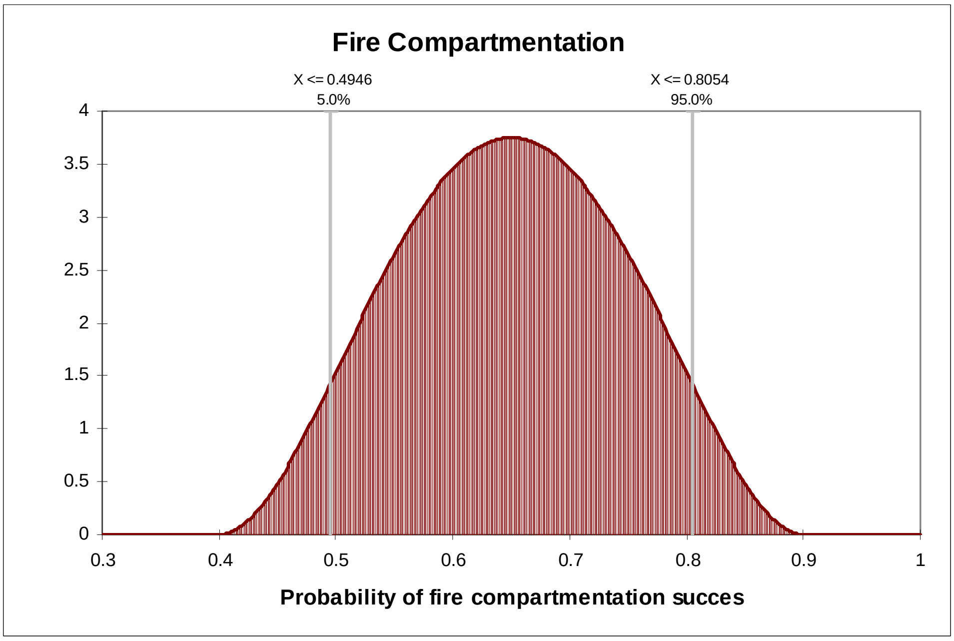


Figure 7.21: Probability density function for fire compartmentation success

7.11.7 Building Model Characteristics

Building height was assumed to be represented by a pert distribution with minimum, most likely and maximum values of 3.5, 5 and 7 m respectively. This is only an estimate by the author and not based on any actual values. The building plan aspect ratio (width : length) was assumed to be represented by a pert distribution with minimum, most likely and maximum values of 1, 3, and 6 respectively. The building height and aspect ratio is used for calculating the required firewall surface area for costs and is an assumption of the author and not based on any data.

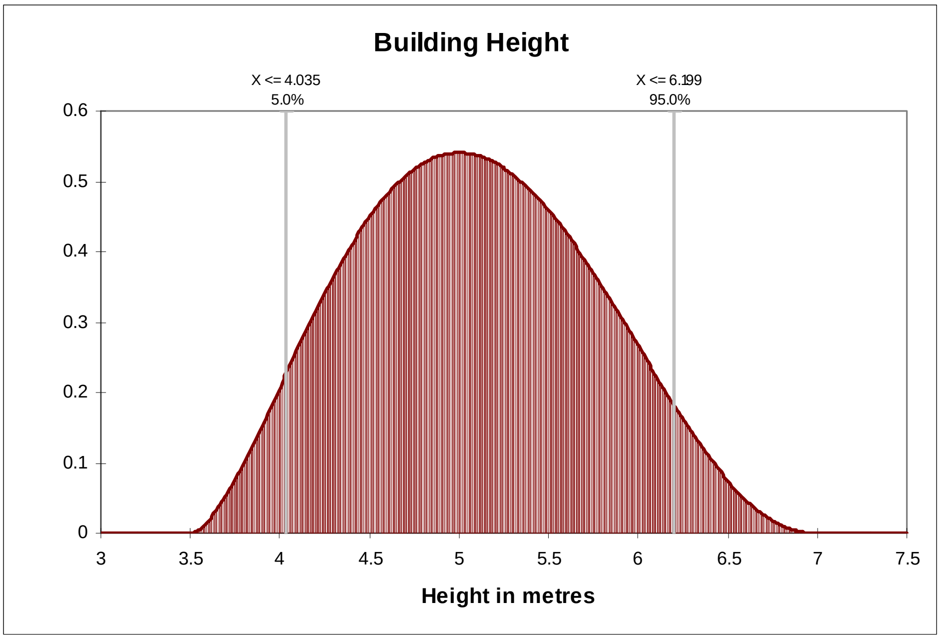


Figure 7.22: Probability density function for building height

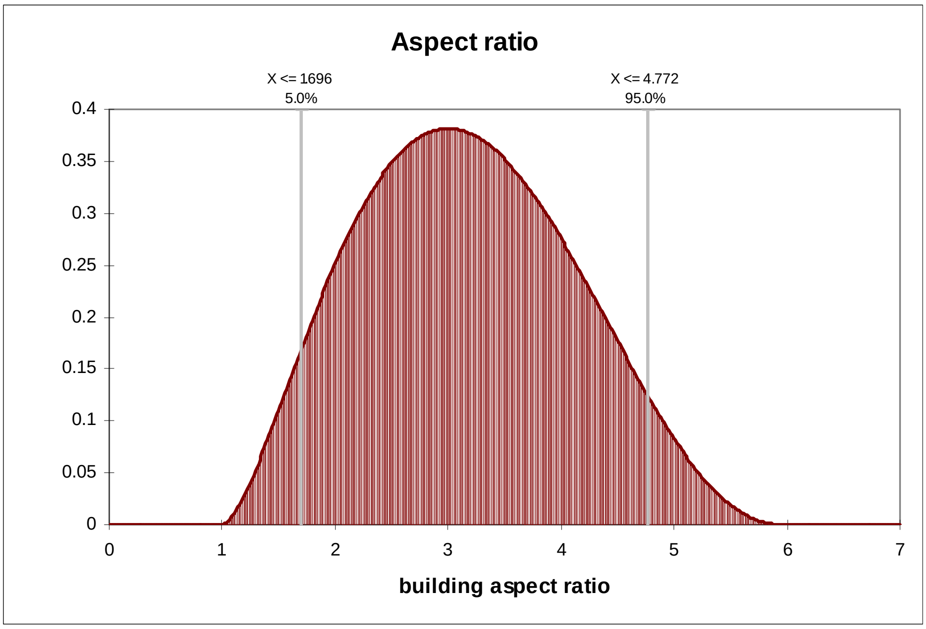


Figure 7.23: Probability density function for aspect ratio

7.11.8 Fire Protection System Costs

Typical costs for fire protection systems were obtained from estimates from the Rawlinson's handbook and installation / maintenance contractors. These costs are described as probability distributions with pert distributions

- Fire Detection fixed costs – Represented by a pert distribution with a minimum value of $2000, most likely value of $3500 and a maximum value of $7000.
- Fire Detection variable costs – Represented by a pert distribution with a minimum value of $9/m^2, most likely value of $11/m^2 and a maximum value of $15/m^2.
- Annual maintenance of the fire alarm system including annual surveys is taken as $700 per year and Fire Service connection costs is taken as $1000 per year.
- Sprinkler system variable costs – Represented by a pert distribution with a minimum value of $35/m^2, most likely value of $55/m^2 and a maximum value of $89/m^2. Sprinkler system maintenance costs are taken as $700 per year which includes annual surveys.
- Fire extinguisher fixed costs – Represented by a pert distribution with a minimum value of $190/unit, most likely value of $220/unit and a maximum value of $280/unit. The costs include the cost of the unit and its installation.
- Fire extinguisher maintenance costs – Represented by a pert distribution with a minimum value of $59/unit, most likely value of $65/unit and a maximum value of 80/unit. The costs include the annual service. A proportional cost for hydraulic testing and signage replacement has been included. It is assumed hydraulic testing and signage costs will occur every 5 years.
- Extinguisher training costs are taken as $34 per person. The total cost of training will require to include refresher training every 2 years and new training due to staff turnover. The average national staff turnover rate is taken as 21% as per the latest survey done by Online Executive Search[62].

- The numbers of extinguishers are determined based on the requirement of NZS 4503:2005.
- Fire cell compartmentation costs - Represented by a pert distribution with a minimum value of $107/m^2, most likely value of $130/m^2 and a maximum value of 164/m^2. Firewall area is calculated as

Firewall area = (number of compartments-1) x building height x SQRT(floor area / aspect ratio)

The following figures represent the pert distributions for fire protection costs estimated above.

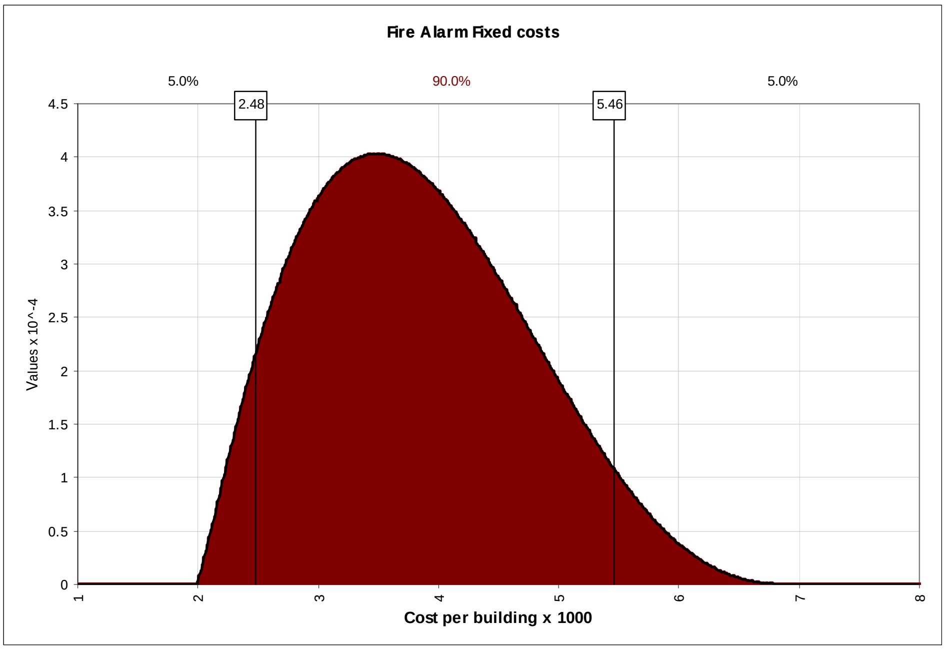


Figure 7.24: Probability density function for fire alarm fixed costs

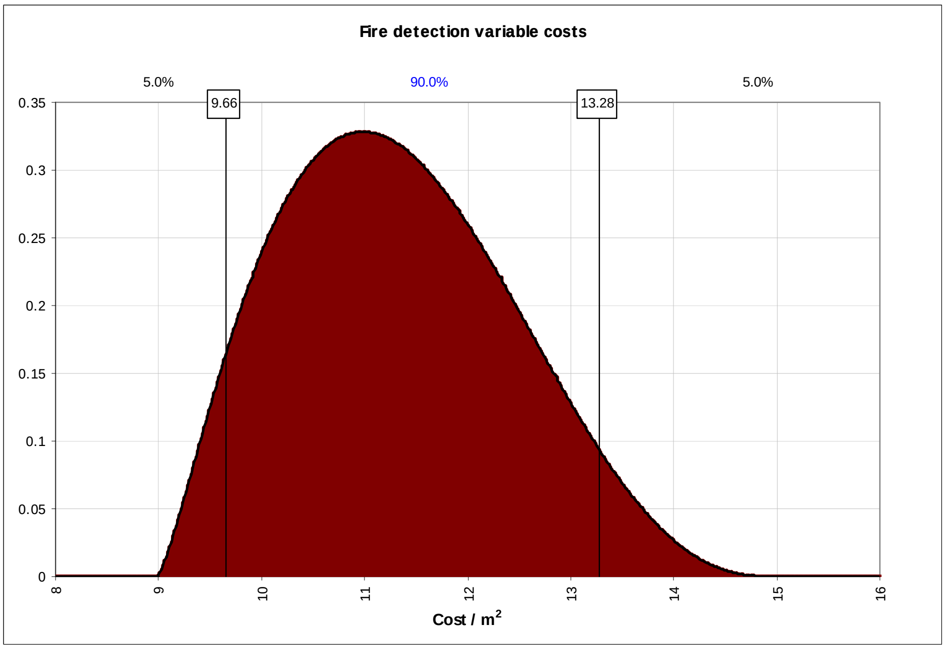


Figure 7.25: Probability density function for fire alarm variable costs

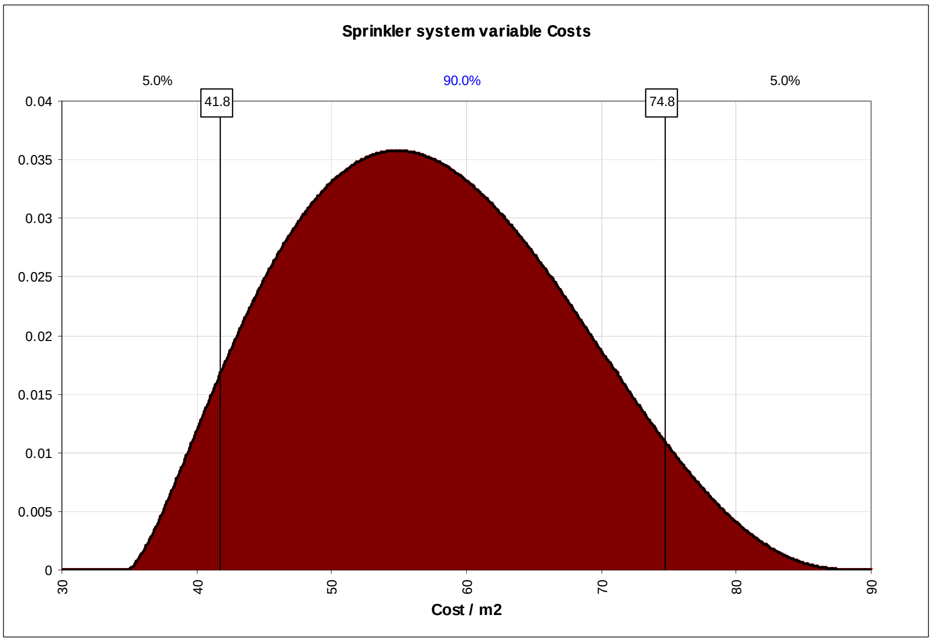


Figure 7.26: Probability density function for sprinkler system variable costs

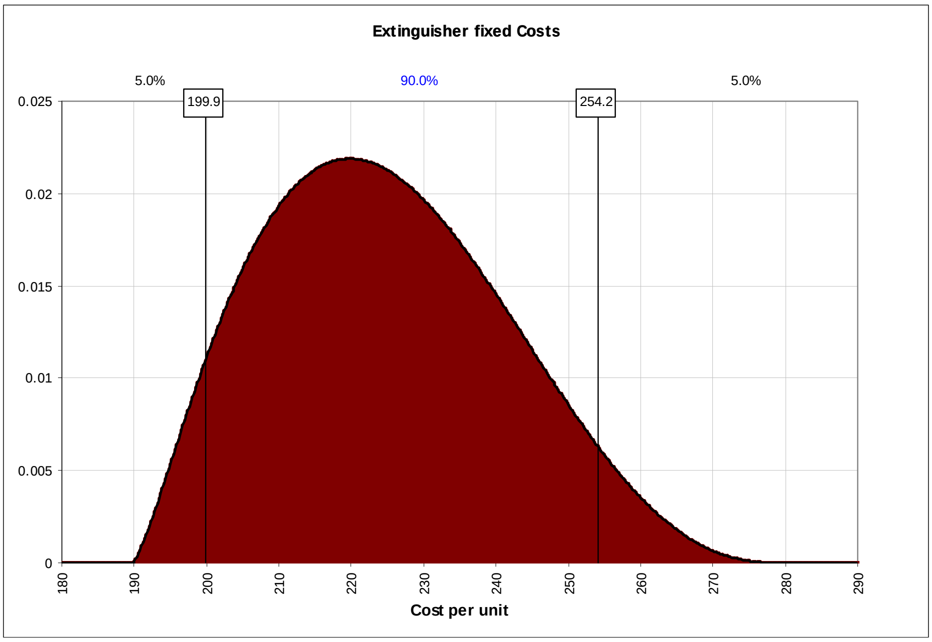


Figure 7.27: Probability density function for fire extinguisher installation costs

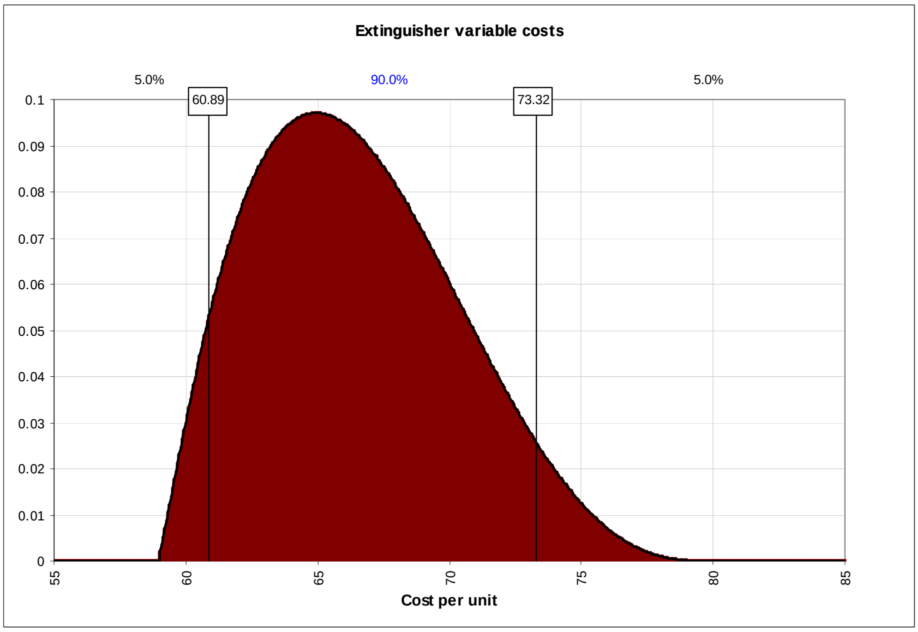


Figure 7.28: Probability density function for fire extinguisher maintenance costs

7.11.9 The Cost of Fires

As discussed previously in section 7.11.1, the average fire loss area was 32m^2 for an unprotected building. Using the estimated costs per fire from Table 7.20, the average cost per m^2 of fire loss is $2886.

Other costs per m^2 using estimated costs per fire from Table 7.20

Business Interruption costs	\$268 per m^2
Other direct economic costs	\$1207 per m^2
Fire Service Costs	\$771 per m^2
Indirect Economic Costs	\$285 per m^2
Reduced consumption Costs	\$70 per m^2
Social Costs	\$285 per m^2

Business interruption costs were estimated by BERL[58] based on insurance claims. Other direct economic costs were actual property and contents damage again based on insurance claims. BERL[58] estimated Fire Service costs on the net operational expenditure on fire fighting and other fire service operations as recorded in their annual report.

Indirect economic costs were attributed to losses to other upstream firms supplying goods and services to the fire affected business and reduced consumption costs were attributed to decrease in consumption as a result of employees and business owners spending less following a decline in sales by the fire affected business.

Social costs are the costs estimated with fire deaths and injuries. As stated by BERL[58], the value of statistical life (VOSL) used was $2,469,900. The average loss of life quality due to serious and minor injuries was estimated to be 10% and 0.4% of the VOSL respectively.

As stated in section 7.9, the cost parameters are represented as normal distributions with the mean value taken as the estimated cost per square metre of fire and a standard deviation equal to 10% of the mean.

The following figures represent the normal distributions for the above costs.

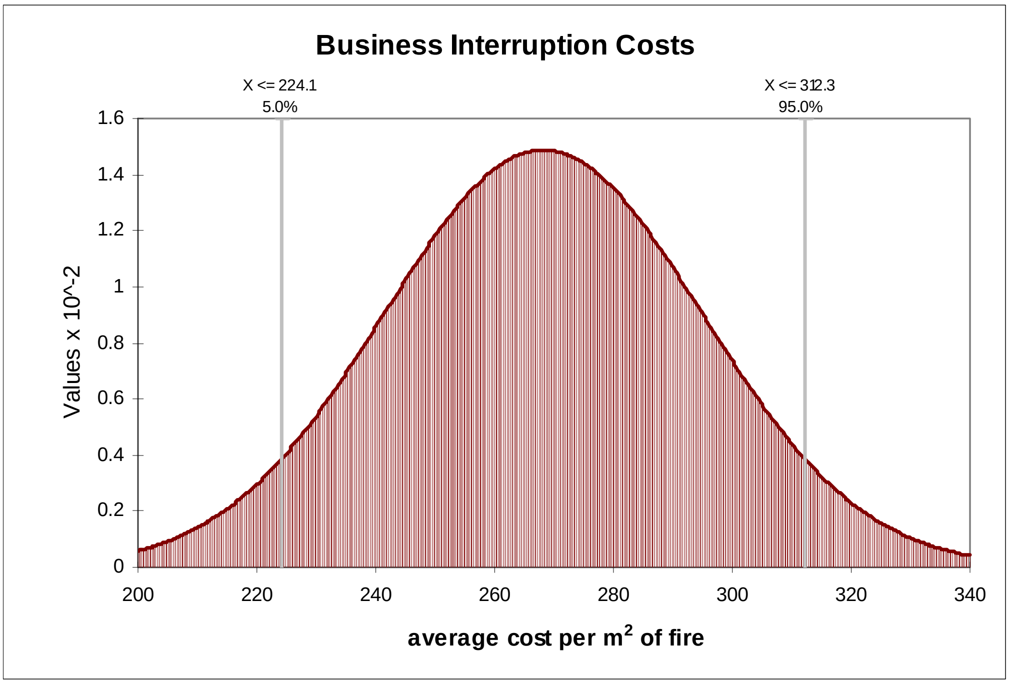


Figure 7.29: Probability density function for business interruption costs

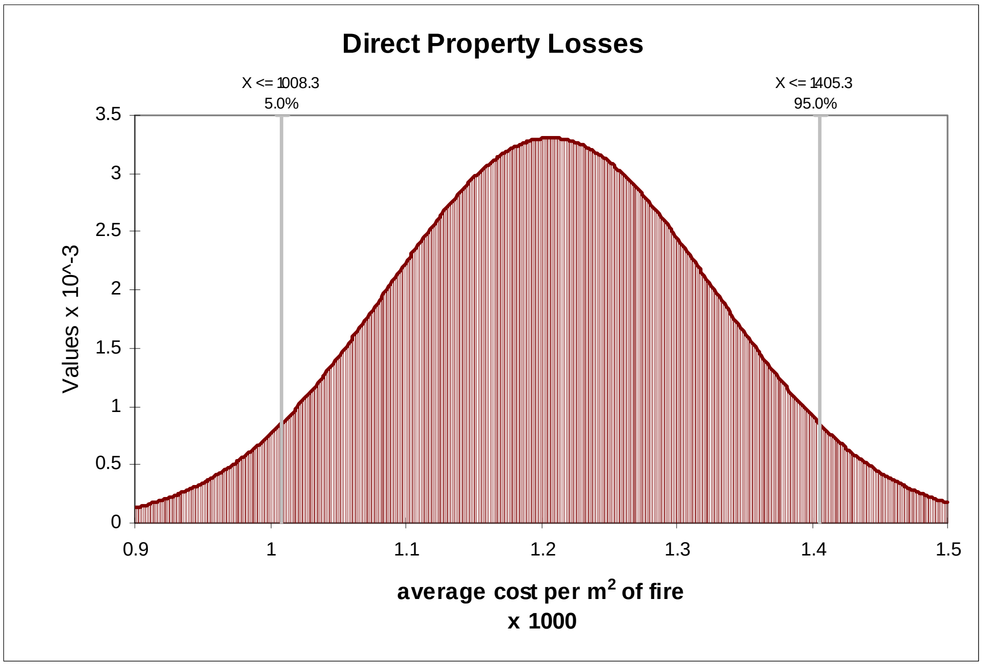


Figure 7.30: Probability density function for other direct economic costs

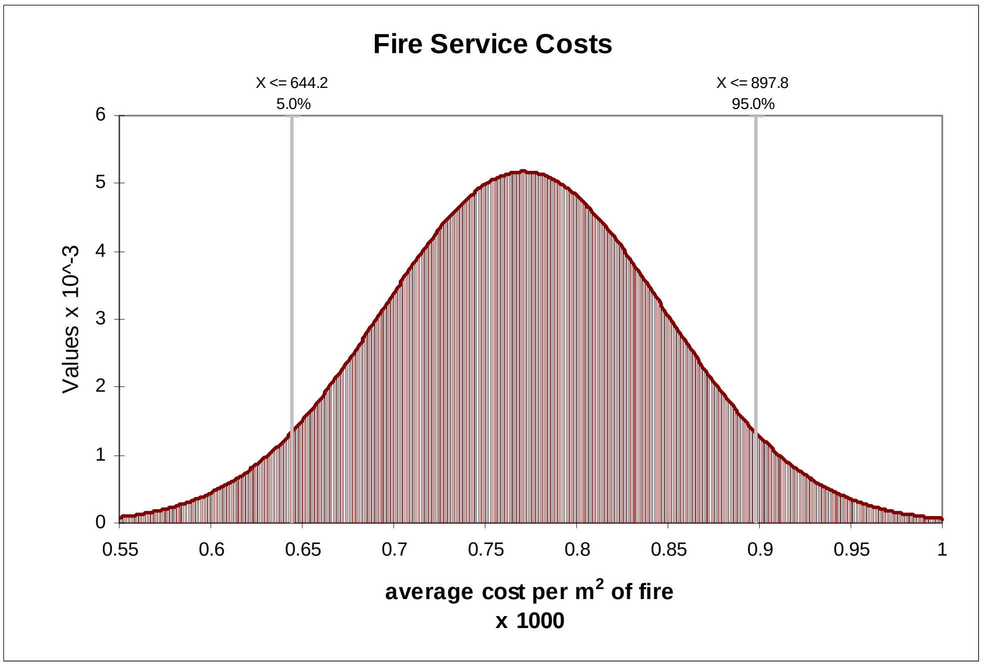


Figure 7.31: Probability density function for fire service costs

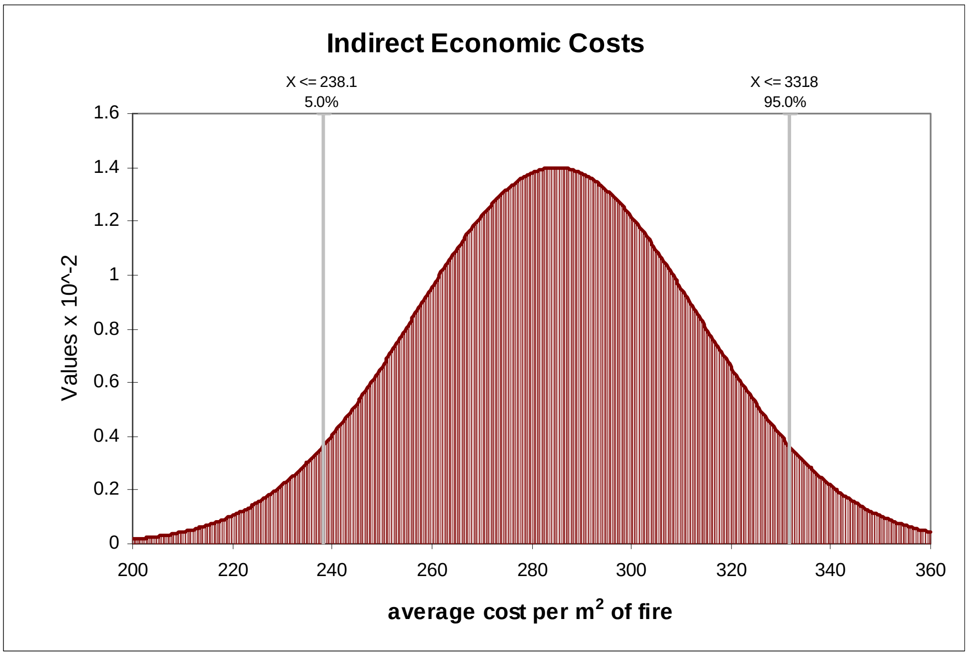


Figure 7.32: Probability density function for indirect economic costs

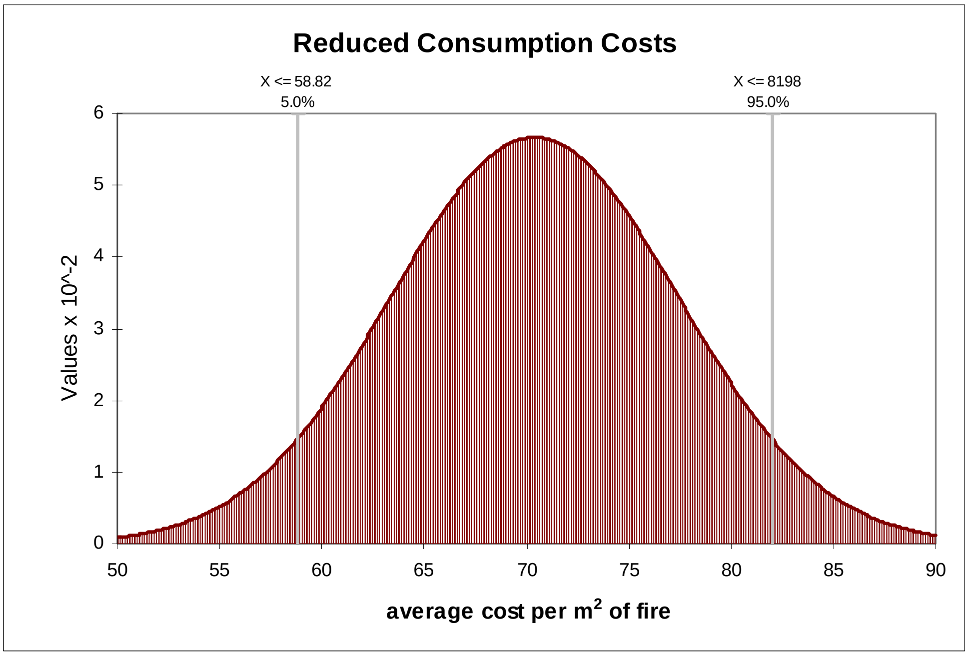


Figure 7.33: Probability density function for reduced consumption costs

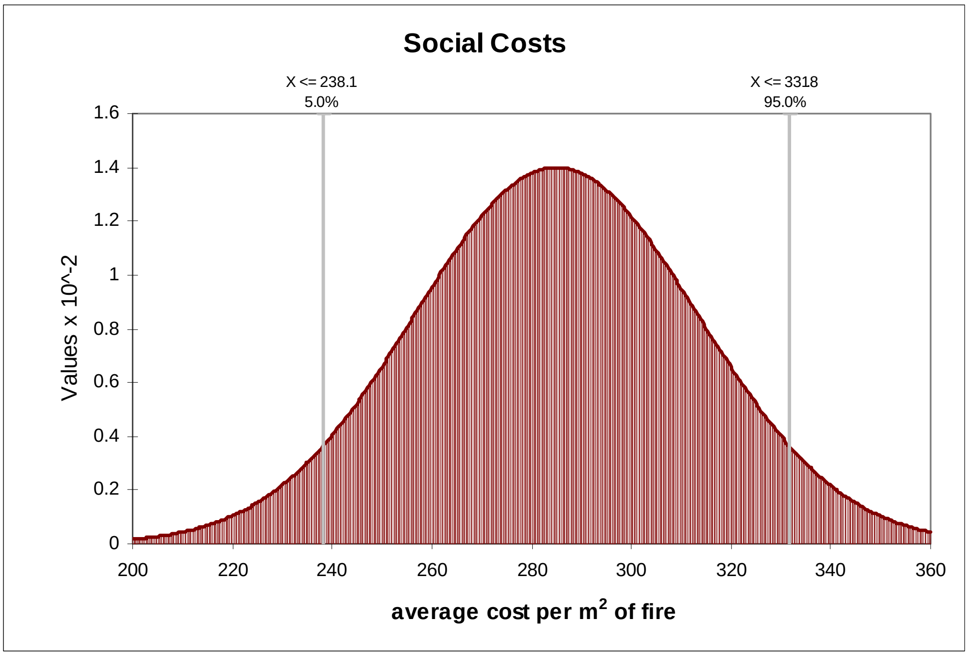


Figure 7.34: Probability density function for reduced consumption costs

7.11.10 Correlation between variables

The risk simulation software @RISK[46] allows dependencies between input variables. This is very useful for a more realistic sampling of input values. The degree of correlation may fall between 0 and 1, 0 being no correlation and 1 being perfect correlation. Positive value indicates that an increase in the input will correspondingly increase the output, whereas a negative value indicates that an increase in the input will decrease the output. The degree of correlation is very subjective and an estimated value was used.

The following dependencies have been used

- The firewall cost is positively correlated with the building height. Taller the building, larger is the wall area and supporting structure,
- Sprinkler installation cost is negatively correlated with building floor area. Larger the building economies of scale will apply,
- Sprinkler installation cost is positively correlated with building height. Taller the building, floor to ceiling height increases, increasing the design fire and thus the sprinkler system,
- Fire alarm system fixed cost is positively correlated to the floor area. Larger floor area will increase the complexity of the system and thus the size of system,
- Fire alarm system variable cost is negatively correlated with building floor area. Larger the building economies of scale will apply.
- Fire extinguisher installation cost is positively correlated with building area. Larger the building more extinguishers are required to provide coverage
- Fire extinguisher maintenance cost is negatively correlated with building area. Larger the number of extinguishers economies of scale will apply.

The assumed degree of correlation is shown in Table 7.23 below.

	Building height	Firewall cost	Floor area	Sprinkler install cost	Fire alarm fixed cost	Fire alarm variable cost	extinguisher install cost	extinguisher maintenance
Building height	1.0							
Firewall cost	0.5	1.0						
Floor area	0.0	0.0	1.0					
Sprinkler install cost	0.6	0.0	-0.5	1.0				
Fire alarm fixed cost	0.0	0.0	0.5	0.0	1.0			
Fire alarm variable cost	-0.4	0.0	-0.4	0.0	0.0	1.0		
extinguisher install cost	0.0	0.0	0.4	0.0	0.0	0.0	1.0	
extinguisher maintenance	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	1.0

Table 7.23: Correlation Matrix

7.11.11 Cost Benefit Inputs

The analysis period is taken as 50 years.

Real discount rate of 5%[63]

Life of fire protection systems and fire walls taken as 50 years.

Using a capital recovery formula for calculating the fire protection initial installation cost as a regular annual payment.

$$A = \frac{P[i(1+i)^N]}{[(1+i)^N - 1]}$$

Where:

A = Regular annual payment

P = Total fire protection installation cost

N = 50 years

i = 5% (=0.05)

The annual maintenance cost & annual training cost was then added to the total cost of fire protection per year.

7.11.12 @ RISK Results

Twenty-five thousand iterations were calculated for each scenario for each building. Each simulation resulted in a convergence of less than 1% change in the calculated mean and standard deviation values. Each iteration sampled the input distributions for each input variable and calculated the "cost of fire per building per year". The results were compared for each building model assumed to have all fire protection systems installed.

The simulations for each building modelled the following scenarios:

1. No fire protection
2. Manual fire suppression following manual detection
3. Manual fire suppression following automatic detection
4. Automatic fire suppression by sprinkler system
5. Compartmentation

The simulations for "no fire protection" investigated the effects of complete damage in a fire without fire service intervention. Fire service intervention has been modelled for a fully involved building with the fire being controlled with 80% damage to the building. "Automatic fire suppression" has investigated three scenarios where sprinklers have suppressed a fire after manual suppression failed, manual suppression was not applied and without any detection.

The cost of fire includes the components of direct property losses, Fire Service costs and indirect losses. Although the direct property loss costs are what a building owner would be interested in, we have included the other costs in the model. The other costs have an economic impact on the whole country and therefore somewhere down the line the building owners share this cost as a part of their business. For example Fire Service costs would have a direct impact of the Fire Service levy charged to building owners. The model also includes the proportion of annual fire protection costs that is applicable to the type of building. The resultant outputs of the model are discussed below.

RESIDENTIAL BUILDING

For a residential occupancy, other than smoke detectors there are no other requirements for fire protection systems to be installed as required by the Building Code. (Refer table 7.19). The scenarios modelled are:

- No fire protection systems installed
- Fire extinguishers available
- Fire extinguishers & domestic smoke alarms installed
- Automatic fire sprinkler system with smoke alarms & fire extinguishers.

The cost for the building fire protection system has been taken based on the specific scenario. Table 7.24 outlines the results of the simulation. Based on the comparison of the expected mean values the "Manual suppression following manual detection" gives the lowest mean cost of fire per year per household. Manual suppression is considered to be the use of an extinguisher for this research.

Scenario	Total cost of fire per year per household (NZ$)		
	Mean	Standard deviation	Upper 95th percentile & rank
No fire protection - complete loss	1620	306	2195(6)
No fire protection - Fire service intervention	775	81	910(5)
Manual suppression following manual detection	77	6	89(1)
Manual suppression following automatic detection	99	18	134(2)
Sprinkler suppression following failure of manual suppression	474	107	673(3)
Sprinkler suppression no manual suppression applied	624	171	927(4)

Table 7.24: Risk Output results for a residential occupancy

Using the upper 95th percentile as the decision criterion, the "Manual suppression following manual detection" gives the lowest cost of fire per year per household. This can be interpreted to mean that in 95% of the cases we expect the cost of fire per year per household to be less than $89 when manual suppression is successful following manual detection. In terms of sprinkler suppression, the cost of a fire is higher if manual suppression is not attempted, which indicates manual suppression may play a role in reducing the losses by reducing the area of damage. Figure 7.35 shows the cumulative distribution of the cost of fire per year per household. Detailed histograms and output values are available in Appendix E.

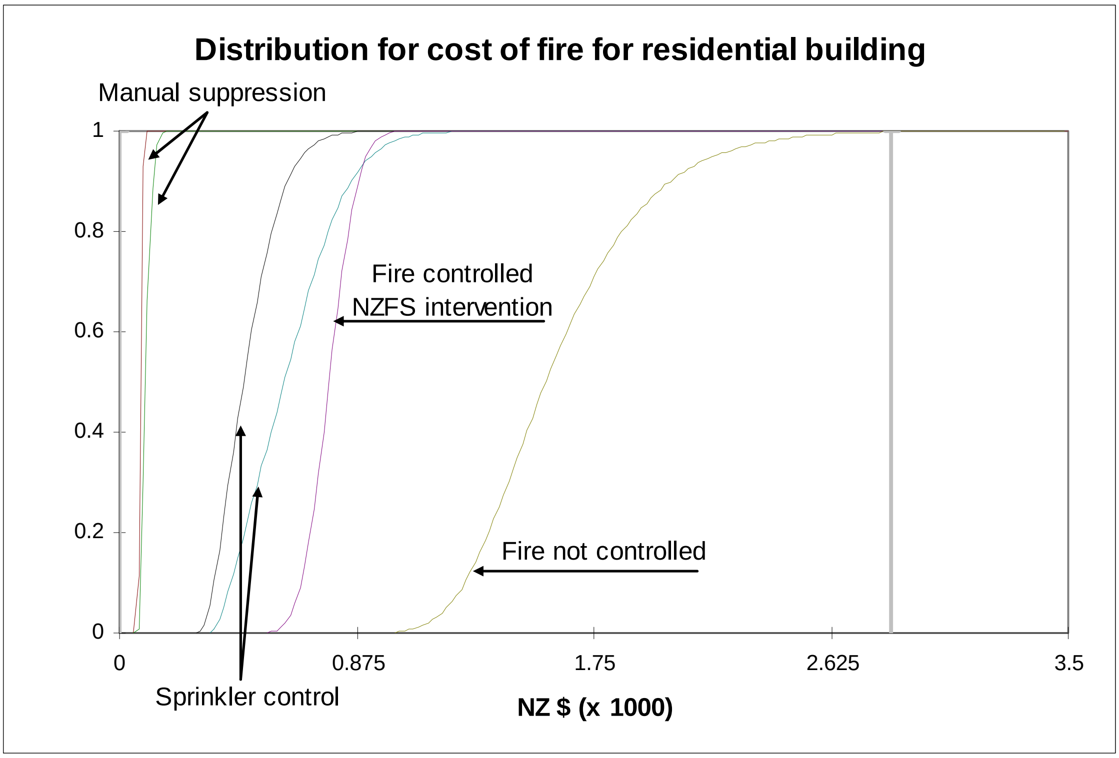


Figure 7.35: Model output distribution for a residential building

CARE FACILITY BUILDING

For a care facility building C/AS1[1]requires the installation of a Type 7 system i.e. an automatic sprinkler system with smoke detectors & manual call points (Refer table 7.19). Although the Building Code does not call up hand operated fire fighting equipment, the sprinkler standard NZS 4541 requires the installation of these equipment. As discussed in section 7.11.1, 80 – 90% of care facility buildings have sprinklers installed. The scenarios modelled are:

- No fire protection systems installed,
- Fire extinguishers used on manual detection,
- Fire extinguishers used on automatic detection,
- Automatic fire sprinkler system operation following manual suppression attempt,

- Automatic fire sprinkler system operation without manual suppression attempt,
- Fire contained in a single fire cell due to sprinkler failure.

The cost for the building fire protection system has been taken as the basic requirements of the C/AS1[1] i.e. a type 7 system with compartmentation of the building. C/AS1[1] considers that in Hospitals and care facilities it may not be possible to evacuate all occupants and therefore it may be designed for a defend in place strategy. The annualised fire protection cost for the building is $ 4167 and an annual training cost of $199. These costs are additional cost to the building owner on top of the annual cost of a fire shown in table 7.25. Table 7.23 outlines the results of the simulation.

Scenario	Cost of property loss per year (NZ$)			Other costs per year (NZ$)	
	Mean	Standard deviation	Upper 95th percentile & rank	Fire Service costs	Indirect Losses
No fire protection (91 - 100% damage)	33428	8645	48393(7)	21048	24800
Fire service intervention (80% damage)	16343	4226	23659(6)	10290	12125
Manual suppression following manual detection	61	44	144(1)	39	46
Manual suppression following automatic detection	253	171	570(2)	161	190
Sprinkler suppression following failure of manual suppression	1985	1025	3865(3)	1268	1494
Sprinkler suppression no manual suppression applied	3502	1641	6337(4)	2237	2636
Fire contained within single compartment due to sprinkler system failure	7178	2904	12636(5)	4520	5325

Table 7.25: Risk Output results for a care facility building

Based on the comparison of the expected mean values the "Manual suppression following manual detection" gives the lowest mean cost of fire loss per year.

Using the upper 95th percentile as the decision criterion, the "Manual suppression following manual detection" gives the lowest cost of fire loss per year. This can be interpreted to mean that in 95% of the cases we expect the cost of fire where manual suppression was successful to be less than $144 (fire detected manually)

The Building Code requires that care facility buildings are provided with a Type 7 system, which includes an automatic sprinkler system with smoke detection and manual call points. Therefore in a care facility the likelihood of detecting a fire is higher when it is relatively small and more likely to be put out using an extinguisher. For a single compartment scenario it is assumed that the fire is contained within the compartment till the Fire Service arrives. It is assumed that the compartment will undergo a complete burnout prior to Fire Service intervention.

Figure 7.36 shows the cumulative distribution of the cost of fire per year per m^2 of fire loss. Detailed histograms and output values are available in Appendix E.

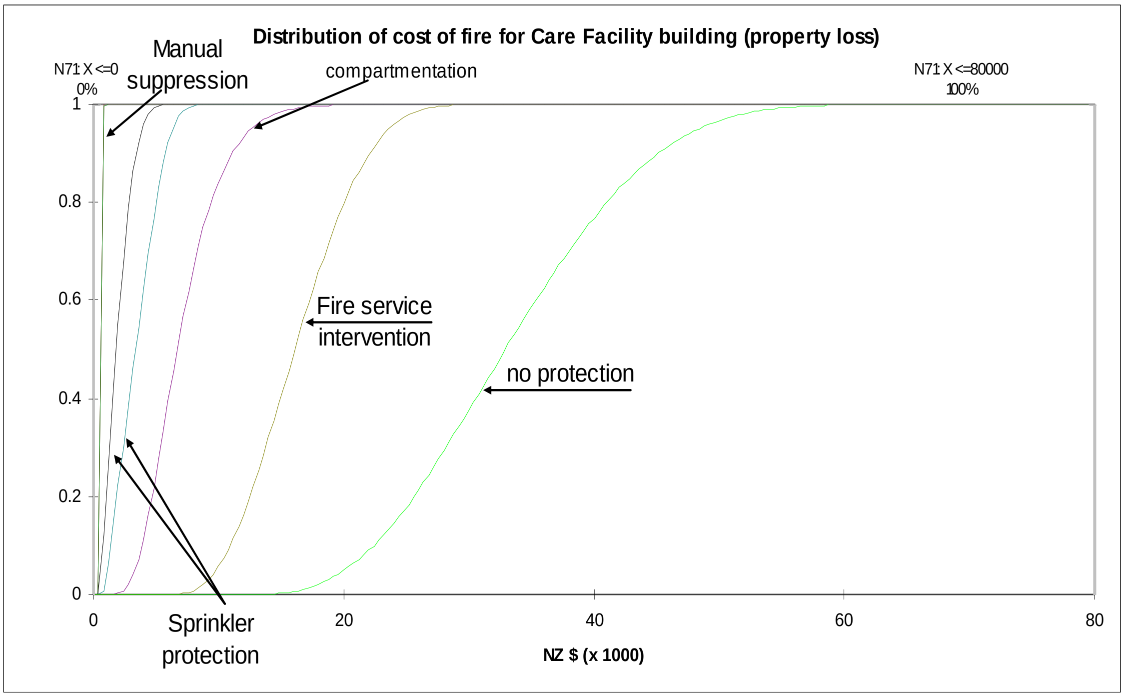


Figure 7.36: Model output distribution for a care facility building

LIGHT COMMERCIAL BUILDING

A light commercial building model is a single level warehouse building with a two level office area. For the purpose of this modelling we have considered the warehouse and offices to be 2 fire cells. For simplicity of the model the warehouse is assumed to be Fire hazard category FHC3. In order for this building to comply with the Building Code the minimum requirement is a Type 2 manual alarm system for both fire cells. This is generally representative of a large proportion of single level light commercial buildings.

For the purpose of this modelling we have assumed portable fire extinguishing equipment is provided within this building. The owner of the building may install sprinklers for property protection purposes. The scenarios modelled are:

- No fire protection systems installed,

- Fire extinguishers used on manual detection,
- Fire extinguishers used on automatic detection,
- Automatic fire sprinkler system operation following manual suppression attempt,
- Automatic fire sprinkler system operation without manual suppression attempt,
- Fire contained in a single fire cell due to sprinkler failure.

For a single compartment scenario it is assumed that the fire is contained within the compartment till the Fire Service arrives. It is assumed that the compartment will undergo a complete burnout prior to Fire Service intervention.

The cost for a building fire protection system to comply with the requirements of the Building Code i.e. a type 2 System (manual fire alarm comprising of manual call points and alerting devices) with compartmentation is $2840 per year. If the building is installed with an automatic sprinkler system, the annualised cost of fire protection is $3963. The annual training costs $695. These are costs additional to the cost of a fire to the building owner. Table 7.26 outlines the results of the simulation.

Scenario	Total cost of property loss per year (NZ$)			other costs per year (NZ$)	
	Mean	Standard deviation	Upper 95th percentile & rank	Fire Service costs	Indirect Losses
No fire protection (91 - 100% damage)	166267	105671	372455(7)	21048	24800
Fire service intervention (80% damage)	58526	37196	131104(6)	37106	43720
Manual suppression following manual detection	201	204	608(1)	129	152
Manual suppression following automatic detection	829	813	2484(2)	530	624
Sprinkler suppression following failure of manual suppression	6498	5425	3865(3)	4160	4902
Sprinkler suppression no manual suppression applied	11474	9161	30025(4)	7341	8650
Fire contained within single compartment	37447	27066	90443(5)	23753	27988

Table 7.26: Risk Output results for a light commercial building

Based on the comparison of the expected mean values the "Manual suppression following manual detection" gives the lowest mean cost of fire loss per year. Using the upper 95th percentile as the decision criterion, the "Manual suppression following manual detection" gives the lowest cost of fire loss per year. This can be interpreted to mean that in 95% of the cases we expect the cost of fire where manual suppression was successful to be less than $608 (fire detected manually)

The cost of a fire to the building owner will vary with the type of fire protection system installed. Therefore if a fire is extinguished manually using an extinguisher (fire detected manually), the total cost of a fire per year will vary from $4017 for a manual (Type 2) system installed to $5140 for an automatic sprinkler (Type 6) system installed. This cost includes the component of fire service costs & indirect losses & training costs.

Figure 7.37 shows the cumulative distribution of the cost of fire per year per m² of fire loss. Detailed histograms and output values are available in Appendix E.

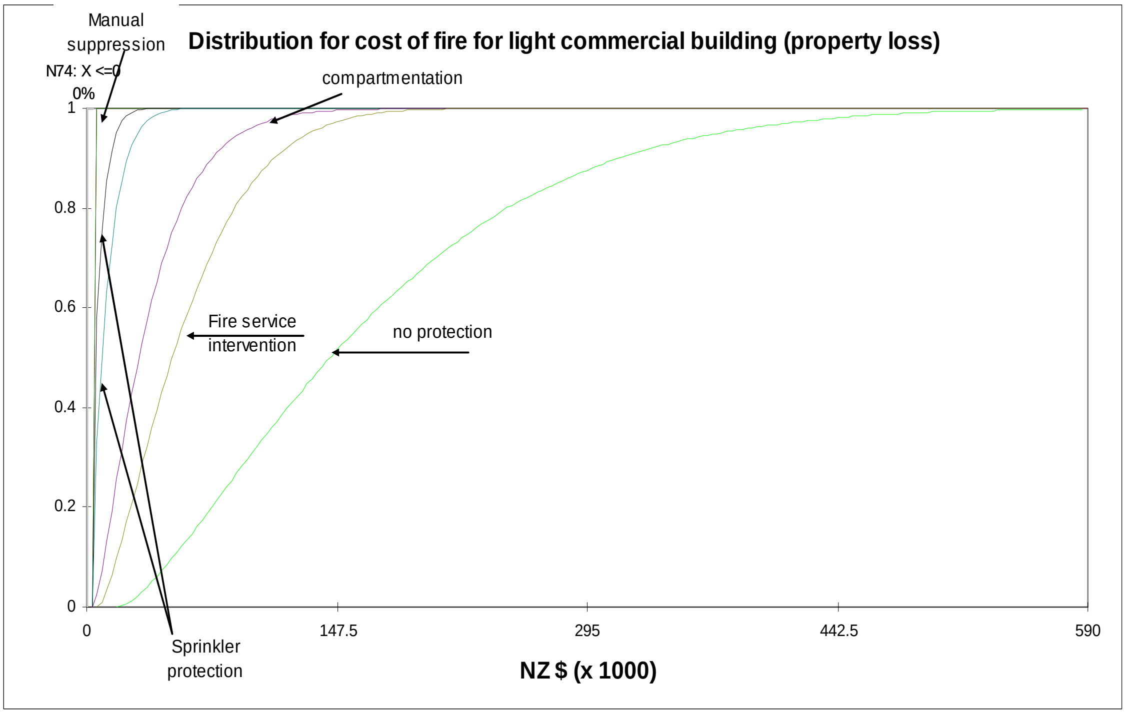


Figure 7.37: Model output distribution for a light commercial building

BULK RETAIL BUILDING

The bulk retail building considered for the modelling is single level with 2 fire cells. The expected storage height is above 3m therefore the fire cells are classified as fire hazard category FHC4. In order for this building to comply with the Building Code the minimum requirement is a Type 3 automatic alarm system with heat detectors for both fire cells. However a large number of such bulk retail units are sprinkler protected especially when they are configured within a shopping mall. The scenarios modelled for this building are:

- No fire protection systems installed,
- Fire extinguishers used on manual detection,

- Fire extinguishers used on automatic detection,
- Automatic fire sprinkler system operation following manual suppression attempt,
- Automatic fire sprinkler system operation without manual suppression attempt,
- Fire contained in a single fire cell due to sprinkler failure.

The single compartment scenario is assumed to have the fire contained within the compartment till the fire service arrives. It is assumed that the compartment will undergo a complete burnout prior to fire service intervention.

The cost for a building fire protection system to comply with the requirements of the Building Code i.e. a type 3 system with compartmentation is $2840 per year. If the building is installed with an automatic sprinkler system, the annualised cost of fire protection is $3963. The annual training costs $695. Table 7.27 outlines the results of the simulation.

Scenario	Total cost of property loss per fire (NZ$)			other costs (NZ$)	
	Mean	Standard deviation	Upper 95th percentile & rank	Fire Service costs	Indirect Losses
No fire protection (91 - 100% damage)	696677	438519	1556631(7)	691864	442025
Fire service intervention (80% damage)	245230	154359	547934(6)	243536	155593
Manual suppression following manual detection	413	420	1258(1)	412	263
Manual suppression following automatic detection	1704	1675	5128(2)	1698	1085
Sprinkler suppression following failure of manual suppression	13313	11504	35502(3)	13334	8519
Sprinkler suppression no manual suppression applied	23540	18731	61555(4)	23530	15033
Fire contained within single compartment due to sprinkler system failure	157055	112914	378000(5)	155900	99603

Table 7.27: Risk Output results for a bulk retail building

Based on the comparison of the expected mean values the "Manual suppression following manual detection" gives the lowest mean cost of fire loss per year. Using the upper 95th percentile as the decision criterion, the "Manual suppression following manual detection" gives the lowest cost of fire loss per year. This can be interpreted to mean that in 95% of the cases we expect the cost of fire where manual suppression was successful to be less than $1258 (fire detected manually)

The cost of a fire to the building owner will vary with the type of fire protection system installed. Therefore if a fire is extinguished manually using an extinguisher (fire detected manually), the total cost of a fire per year will vary from $4908 for a manual (Type 3) system installed to $7208 for an automatic sprinkler (Type 6) system installed. This cost includes the component of fire service costs & indirect losses & training costs.

Figure 7.38 shows the cumulative distribution of the cost of fire per year per m^2 of fire loss. Detailed histograms and output values are available in Appendix E.

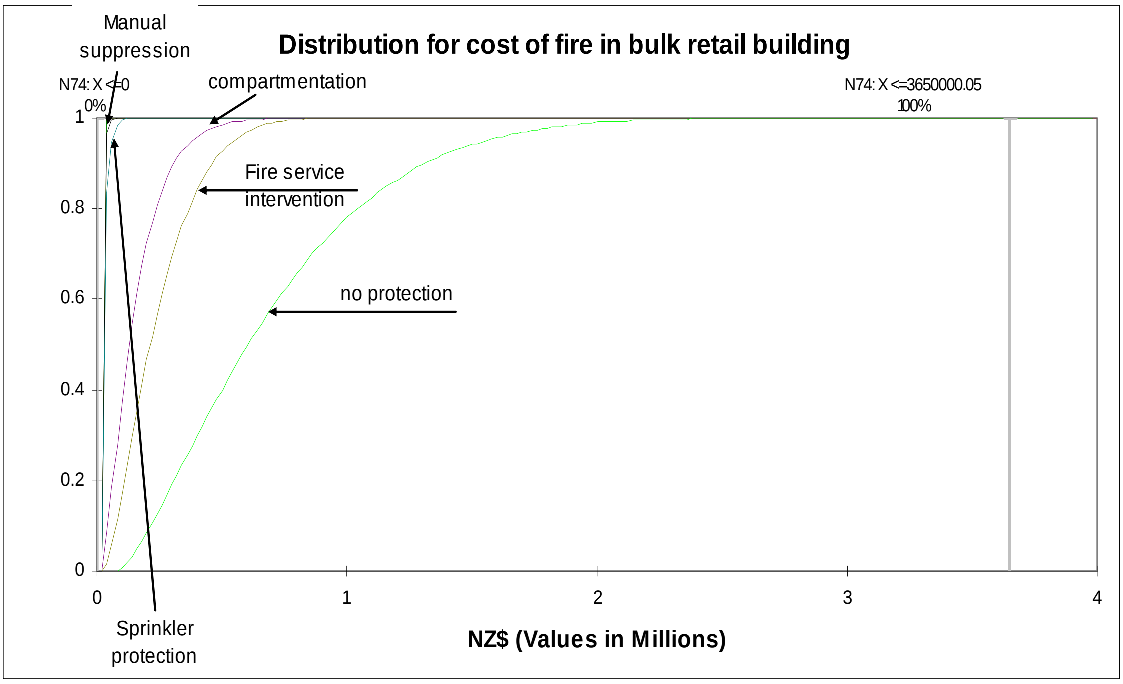


Figure 7.38: Model output distribution for a bulk retail building

7.11.13 Comparison with Historical Data

As a check, the model results have been compared with estimated cost of fires researched by BERL[58]. It was estimated that the total direct property losses due to a fire in year 2000 to be $36 million (Section 7.11.9). This was based on 1100 structure fires, which gives an average property loss per incident at $32,727. It was further estimated that an average fire loss area would be 32m^2 per fire. Therefore the average property loss per m^2 is $1023.

BERL[58] estimated property damage based on New Zealand Fire Service Statistics as shown in the table below.

EXTENT OF DAMAGE 2000	Total Incidents	% of All Fire Incidents	Total Area Lost	% of Total Area Lost
Extent of damage (% of structure lost)	**(Number)**	**(%)**	**(M^2)**	**(%)**
91% to 100%	101	9%	16,181	46%
51% to 90%	42	4%	6,970	20%
11% to 50%	140	13%	6,552	19%
0% to 10%	817	74%	5,352	15%
Total	**1,100**	**100%**	**35,056**	**100%**

Source: FIRS, BERL

Figure 7.39: Composition of property damage in 2000, BERL

From table 7.39, the average area lost per incident for 0% – 10% damage to a structure is equivalent to 6.5 m^2. In section 7.11.2 we have estimated fire loss area due to manual suppression to be between 1 to 3 m^2. The cost estimated for 0% to 10% damage is approximately $6701 per incident ($1023 x 6.5 m^2). The risk model predicts property loss for manual suppression to range between $144 (care facility buildings) to $1353 (bulk retail) using the 95th percentile value.

From table 7.39, the average area lost per incident for 10% – 50% damage to a structure is equivalent to 47 m^2. In section 7.11.3 we have estimated fire loss area due to sprinkler suppression to be between 3 to 20 m^2. The cost estimated for 10% to 50% damage is approximately $47876 per incident ($1023 x 47m^2). The risk model predicts property loss for manual suppression following detection to range between $6337 (care facility buildings) to $14973 (bulk retail) using the 95th percentile value.

It is reasonable to assume that the predicted property losses from the risk model will be much lower than the estimated property losses using the BERL & FIRS data. This difference may be attributed to the increased loss area included in the BERL-FIRS data. It may be noted that the BERL-FIRS data is for Y2000 and the estimated cost increase to Y2007 is taken as 18% (Refer section 7.9)

7.11.14 Sensitivity Analysis

A regression sensitivity was done with the analysis. With this analysis, the rank correlation is calculated between the selected output variable and the samples for each input variable. The higher the correlation between the input and output, the more significant the input is in determining the output values.

Figure 7.40 to figure 7.56 show tornado plots of the standard b coefficients for the various fire scenarios. The plots are for a bulk retail building which indicate that the outputs are most sensitive to fire initiating likelihood.

Detailed tornado plots & correlation coefficients all the other building types are provided in Appendix E.

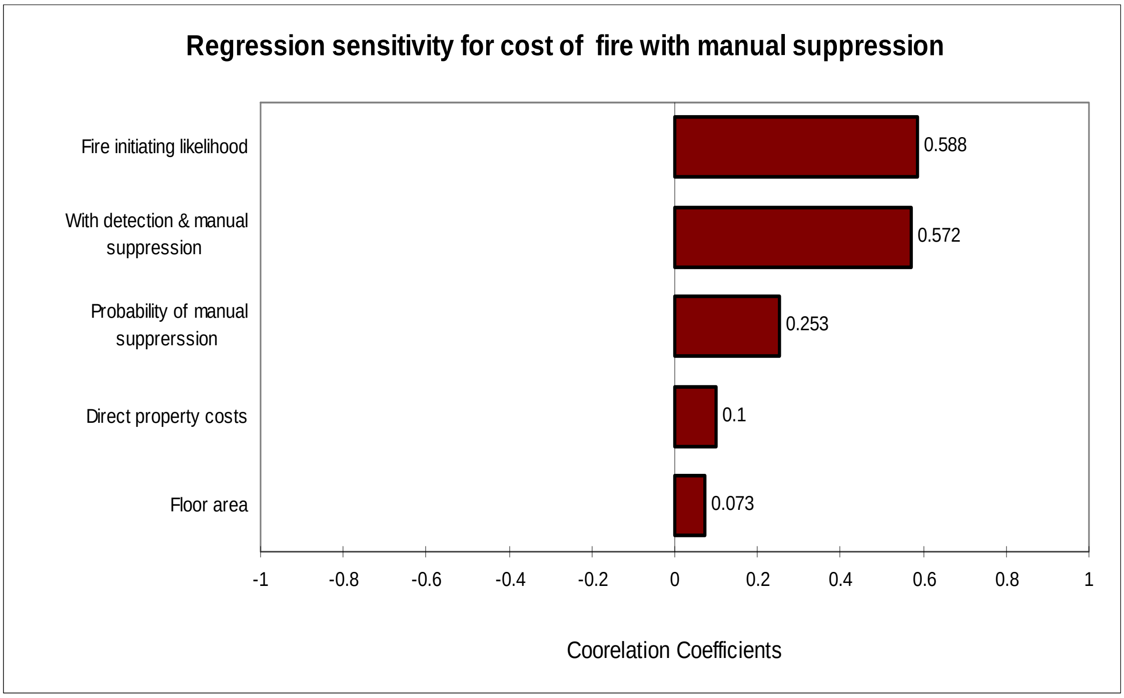


Figure 7.40: Sensitivity analysis for cost of fire using manual suppression

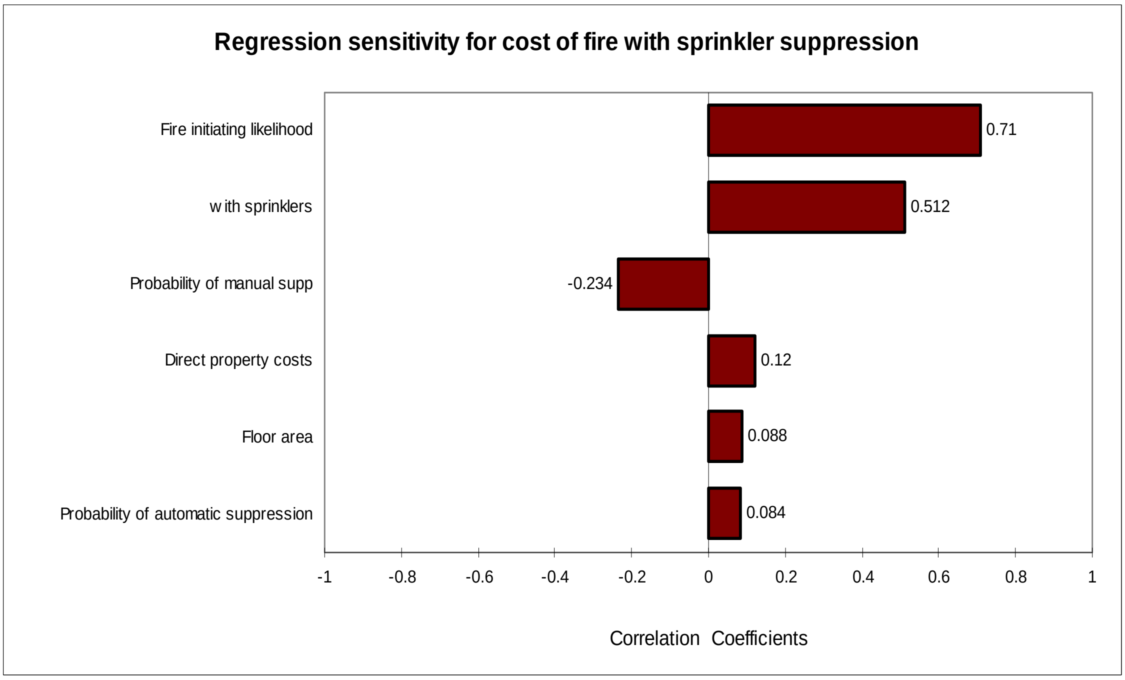


Figure 7.41: Sensitivity analysis for cost of fire using sprinkler suppression

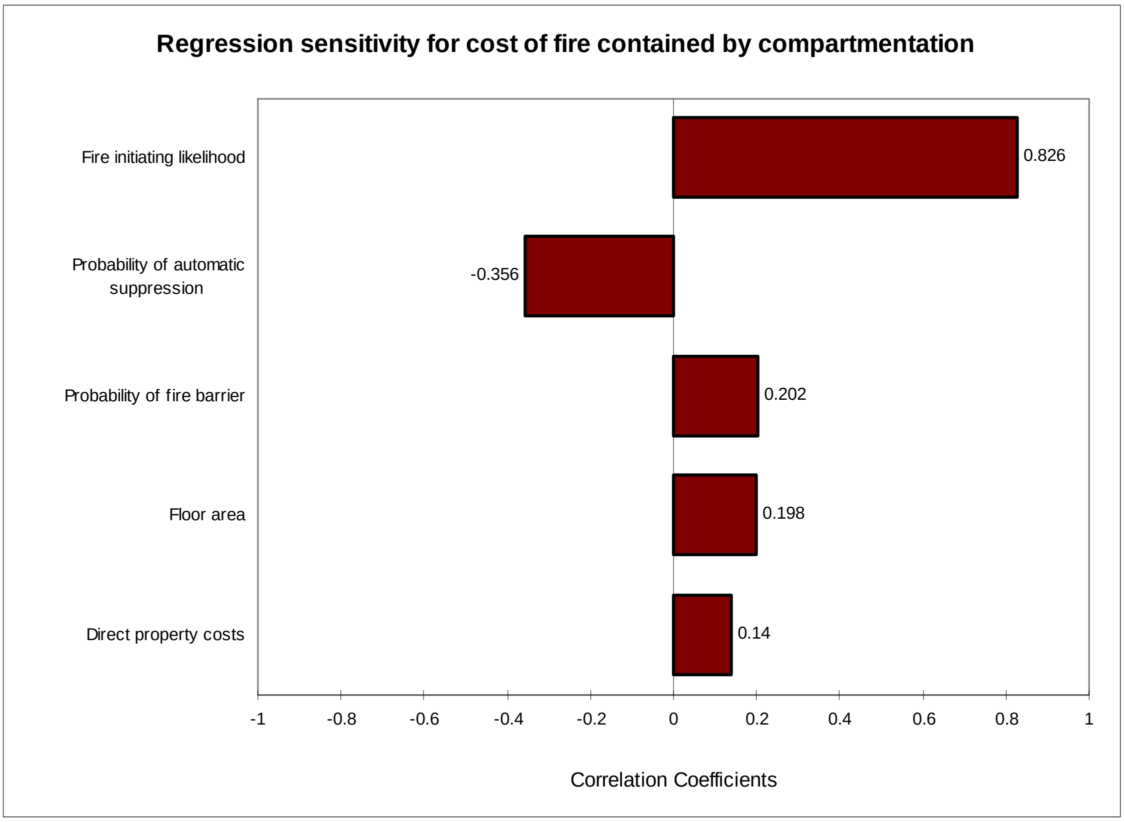


Figure 7.42: Sensitivity analysis for cost of fire contained by compartmentation

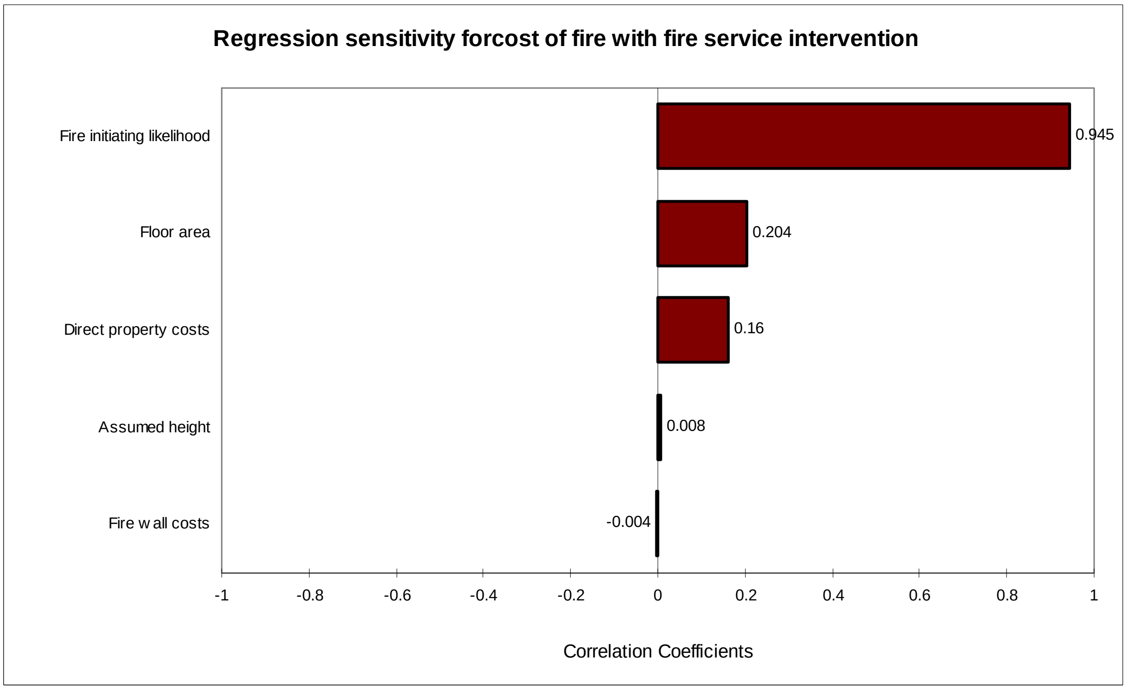


Figure 7.43: Sensitivity analysis for cost of fire suppressed by Fire Service

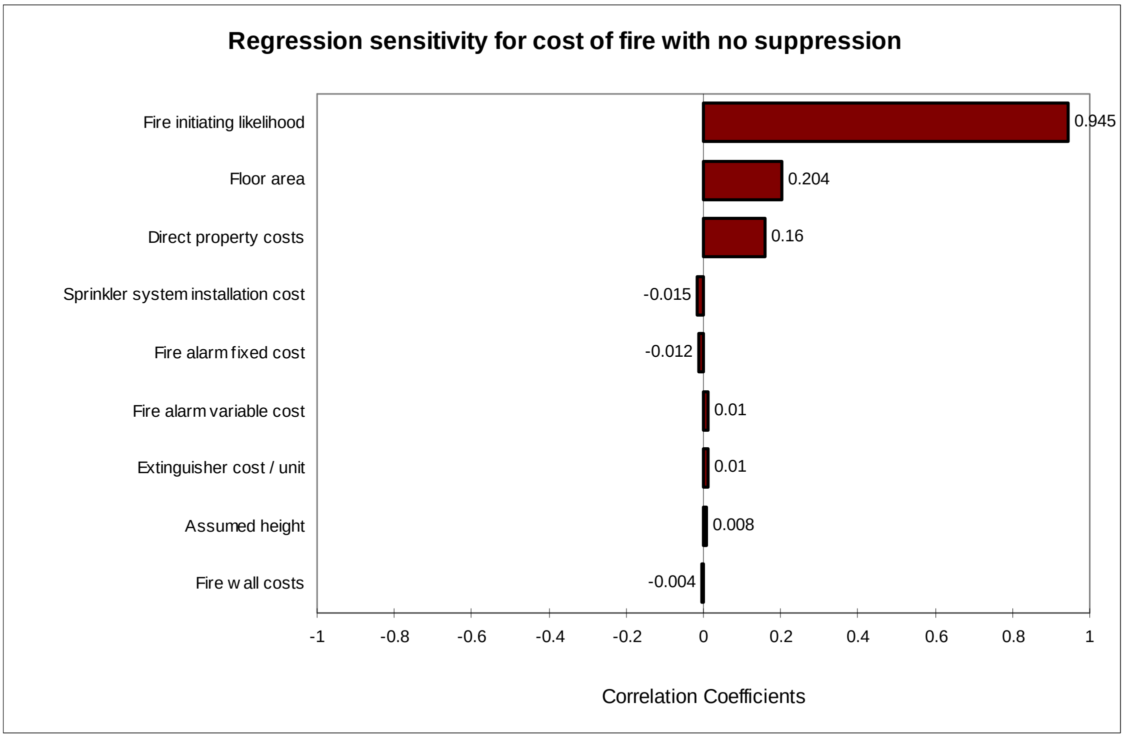


Figure 7.43: Sensitivity analysis for cost of fire with no suppression

7.11.15 Model limitations

The model and the subsequent analysis method used rely on data from previous research and study. The model parameters based on this data will therefore require considering that the change in this data will have an effect on the results. The following input data to the model is highly reliant on other research and study.

1. The model parameters for fire loss costs are directly corresponding to the earlier Business Economic Research limited (BERL) analysis.
2. The fire loss area for different scenarios is based on other studies and assumptions. Fire loss area for manual suppression is based study by Ramachandran, loss area for sprinkler suppression on BERL/BRANZ study, loss area for compartmentation on BRANZ study. Fire loss area

for complete burnout and fire service intervention is based on comparison of data recorded for structure fires by the New Zealand Fire Service (NZFS) and comparing it with BERL data.

3. The fire initiating event is based upon NZFS data for Y 2003-04. There has been a reduction in fires in some building types.

The model has also considered all the buildings of the specific occupancy to have all fire protection systems installed. In reality many buildings especially older ones may not have all systems installed. Therefore in buildings where a sprinkler system or compartmentation is not installed, the benefits of a fire extinguisher installation may become significant.

7.11.16 Results

The risk analysis and literature review highlights the following benefits of fire extinguisher installations:

1. Fire extinguishers are generally not required under a C/AS1[1] design for compliance with the Building Code, however other regulations may require the installation of these equipment in most buildings,
2. Portable fire extinguishers will provide additional protection while the building is occupied in all occupancy classes,
3. Fire extinguishers can significantly reduce losses resulting from a fire incident if used successfully to extinguish a fire in its initial stages.

8 Possible Future Study

- Better data on fire loss areas for different occupancies in New Zealand. This study was based on data presented by Business Economic Research Ltd (BERL) and the New Zealand Fire Service (NZFS). The use of percentage property saved data from the NZFS was an estimate provided by the attending fire officer and there is some scepticism over the accuracy of these figures. Better data on fire loss areas for buildings with different fire protection installation is also essential. In the absence of quality data, this study has used engineering judgement in making assumptions for the modelling.
- Review estimates of fire damage costs with data from Insurance agencies. This study has used data presented by BERL in 2002 and interpolated it to year 2007 figures using a multiplication factor. Current data available from Insurance Council of New Zealand is a combined claims data and does not reflect losses from fire incidents.
- The 2002 European survey stated that 75% of documented incidents did not require the attendance and resources of the fire service. This was estimated to be a saving of £ 1.5 million each year in terms of fire service resources. The New Zealand survey conducted as a part of this study as well as the previous survey done by NZFS provides a very similar outcome in terms of incidents not required to attend by the fire service (89.9%). Further work needs to be done with the fire service to determine any cost saving in fire service resources. More importantly whether attending the additional incidents would overwhelm the current fire service resources. It is understood that the NZFS has a significant number of volunteer brigades that form part of the operations. Current statistics show that the NZFS has 7000 urban volunteer fire fighters compared to 1700 career fire fighters.

- Study other hand operated fire fighting equipment benefits (like hose reels)
- Further study to include human behaviour in understanding action and reaction mechanisms for an individual discovering a fire for both male and female. Factors involving training in use of extinguishers to record change in action / reaction mechanisms. This is important because successful use of a portable extinguisher depends on early discovery of a fire and subsequent use of the correct extinguisher.

9 Conclusion

Based on the risk model analysis and considering an upper 95 percentile decision criterion for all the model buildings, the expected cost of fire when a fire is suppressed manually following detection (manual or automatic) is estimated to be the lowest. The expected fire costs include an annualised cost for fire protection installation for the building which is based on a capital recovery formula.

The Fire extinguisher usage survey 2008 results has shown a trend which is very similar to the European Survey in 2002[10] and the earlier 2003-04 survey[31] done by the Fire Service for New Zealand. These results are summarized as

- In approximately 94% of the incidents recorded, a portable fire extinguisher is totally effective in containing & suppressing a minor fire.
- In 89.9% of the known incidents where fire extinguishers are used, the Fire Service has not been called.
- In approximately 86% of the incidents a fire extinguisher was used by the building owner / occupier.
- Approximately NZ$ 14915 was recorded as damage from the recorded 144 fire incidents. This would give an average NZ$ 104 per incident. This information was not provided for a small proportion of incidents.

Both the risk modelling & the extinguisher usage survey confirm the generally accepted fire protection principle; a well maintained active system (Fire Alarms and Sprinklers) and other passive systems (Fire Separation etc.) provide the building with a high degree of fire safety both in terms of life safety and property protection at all times. Portable Fire Extinguishers will provide additional protection while the building is occupied and it can significantly reduce losses resulting from a fire incident if used successfully to extinguish a fire in its initial stages.

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Appendix A

Extract from Compliance Document C/AS1, October 2005 & New Zealand Sprinkler Standard NZS 4541:2007

Table 4.1: **Fire Safety Precautions**
Key to table references

Part 3	Paragraphs 3.1.5, 3.13.1 and 3.19.2
Part 4	Paragraphs 4.3, 4.3.1, 4.3.3, 4.4.1, 4.5.2, 4.5.3, 4.5.4, 4.5.7, 4.5.8, 4.5.9, 4.5.10, 4.5.13, 4.5.14, 4.5.15, 4.5.19
Part 5	Paragraphs 5.5.1, 5.6.6, 5.6.8, 5.9.4 c)
Part 6	Paragraphs 6.2.1, 6.4.1, 6.7.1, 6.8.1, 6.8.5, 6.8.6, 6.10.1, 6.11.1, 6.15.1, 6.19.9, 6.21.2, 6.23.1 d), 6.23.2, 6.23.3
Part 8	Paragraphs 8.2.1, 8.2.2, 8.2.3
Appendix A	Paragraphs A1.1.1 and A1.1.2

Fire safety precautions

Type	Description
1	Domestic smoke alarm system.
2	Manual fire alarm system.
3	Automatic fire alarm system with heat detectors and manual call points.
4	Automatic fire alarm system with smoke detectors and manual call points.
5	Automatic fire alarm system with modified smoke/heat detection and manual call points.
6	Automatic fire sprinkler system with manual call points.
7	Automatic fire sprinkler system with smoke detectors and manual call points.
8	Voice communication system.
9	Smoke control in air handling system.
10	Natural smoke venting.
11	Mechanical smoke extract.
12	No Type 12 currently specified.
13	Pressurisation of safe paths.
14	Fire hose reels.
15	Fire Service lift control.
16	Emergency lighting in exitways.
17	Emergency electrical power supply.
18	Fire hydrant system.
19	Refuge areas.
20.	Fire systems centre.

Special applications

a Not required where:

i) the *escape routes* serve an *occupant load* of no more than 50 in *purpose groups* CS (excluding *early childhood centres*), CM, WL, WM, WH and WF, or

ii) the *escape routes* are for *purpose group* SA and serve no more than 10 beds, (or 20 beds for trampers huts, see Paragraph 6.20.6), or

iii) exit doors from *purpose group* SA and SR *firecells* open directly onto a *safe place* or an external *safe path* (see paragraph 3.14).

b Where only a single *escape route* is available, no less than a Type 4 alarm is required. See Paragraph 3.15.3 for situations where sprinklers are required.

c Required where Fire Service hose run distance, from the Fire Service vehicular access (see Paragraph 8.1.1) to any point on any floor, is greater than 75 m.

d Emergency lighting extended to *open paths* throughout the *firecell*.

e Type 5 is permitted as an alternative alarm system within *firecells* containing sleeping accommodation. (See Appendix A for description of Type 5.)

f A direct connection to the Fire Service is not required provided a telephone is installed and freely available at all times to enable 111 calls to be made.

Note:

The numbered references are more fully explained in Appendix A.

Throughout Table 4.1 dark shading identifies where sprinklers are required.

Extracted from the Compliance Document, C/AS1; Oct 2005 issued by the Department of Building and Housing

Figure A1: Fire Safety Precautions prescribed under the Building Code

Table 4.1/5: Fire safety precautions for sleeping purpose group firecells
Occupant load 40 maximum

		Escape height							
Purpose Group	**FHC**	**0 m (or single floor)**	**<4 m (or two floors)**	**4 m to <10 m**	**10 m to <25 m**	**25 m to <34 m**	**34 m to <46 m**	**46 m to <58 m**	**over 58 m**
SC SD	1	**F0**	**F30**	**F30**	**F30**	**F30**	**F45**	**F45**	**F60**
		7 16d 18c	7 16d 18c	7 16d 18c	7 9 15 16d 18	7 8 9 13 15 16d 18 20	7 8 9 13 15 16d 18 20	7 8 9 13 15 16d 18 20	7 8 9 13 15 16d 17 18 19 20
SA (Note 5)	1	**F0**	**F45**	**F45**	**F45**	**F30**	**F45**	**F45**	**F60**
		4aef 16a 18c	4ef 16a 18c	4e 14 16a 18c	4e 14 15 16 18	7e 8 9 15 16 18	7e 8 9 13 15 16 18 20	7e 8 9 13 15 16 18 20	7e 8 9 13 15 16 17 18 20
SR (Note 7)	1	**F0**	**F45**	**F45**	**F45**	**F30**	**F45**	**F45**	**F60**
			2a	2f 16a	4e 14 16 18	7e 15 16 18	7e 15 16 18	7e 15 16 18 20	7e 13 15 16 18 20
Column		1	2	3	4	5	6	7	8

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* a *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** *Purpose group* SA may have an *occupant load* up to 160 beds in *firecells* with a Type 7 alarm (see Paragraph 6.7.2).
6. **Occupant load in SC and SD firecells:** The *occupant load* in a *group sleeping area firecell* is limited to 12 or 20 beds and in a *suite* to six beds (see Paragraphs 6.6.3 to 6.6.5). For *firecells* (such as an operating theatre) required to remain occupied during a *fire*, see Paragraphs 5.6.8 and 5.6.9.
7. **SR household units:** See Paragraph 6.8.6 which describes where *household units* containing upper floors may be treated as single floor *firecells*.

Extracted from the Compliance Document, C/AS1; Oct 2005 issued by the Department of Building and Housing

Figure A2: Fire hose reels prescribed as a Fire Safety Precaution

Appendix D: Fire Sprinkler Systems

D1.1 Introduction

D1.1.1 Wherever sprinklers are required by this acceptable solution, they shall comply with the relevant New Zealand Standard, amended as shown in Paragraphs D2.1 and D3.1.

D2.1 Automatic Fire Sprinkler Systems

Amend 4 Oct 2005

D2.1.1 NZS 4541: 2003 is amended as follows:

Clause 103 DEFINITIONS

Amend 4 Oct 2005

Sprinkler system A system including:

(a) to (j) No change.

(k) Delete.

(m) Delete.

Amend 4 Oct 2005

Clause 109 Delete entire clause.

Amend 4 Oct 2005

Clause 205 Delete entire clause.

Clause 208 Delete entire clause.

Clause 601.2 Sprinkler systems shall have a water supply complying with no less than the requirements for Class C water supplies. Where additional water supplies are provided they shall comply with the requirements for Class A, Class B1 or Class B2 as applicable.

Clause 601.4 Delete.

Clause 601.5 Delete.

Clause 1203 ROUTINE SURVEYS

Clause 1203.1 It is important that a sprinkler system at all times complies with this Standard as amended by Paragraph D2.1 of Appendix D to C/AS1 in all respects. To ensure that *building alterations*, changes in process or storage patterns or progressive deterioration of system components do not prejudice system compliance, a comprehensive survey shall be carried out biennially at intervals not exceeding 28 months. Such surveys shall be carried out by an independent qualified *person*.

Extracted from the Compliance Document, C/AS1; Oct 2005 issued by the Department of Building and Housing

Figure A3: Amendments to NZS 4541:2003 under the Building Code

208 PROVISION OF HAND OPERATED FIREFIGHTING APPLIANCES

208.1

Throughout the occupiable area of a sprinkler protected building or sprinkler protected firecell, hand operated firefighting equipment shall be provided to the requirements of NZS 4503.

NOTE –

(1) This clause is not a requirement for a sprinkler system to comply with the Compliance Documents of the New Zealand Building Code.

(2) Hand operated firefighting appliances are a necessary adjunct to sprinkler protection. Their main use is in the extinguishment of fires in the incipient stages before the sprinklers are brought into operation and also for final extinguishment of the small remnants of combustion which may not have been completely extinguished following the operation of the sprinklers.

208.2

Extra high hazard storage risks shall be provided with a minimum of 25 mm hose instead of other options allowed by NZS 4503.

NOTE –

(1) Although conventional hose reels are unlikely to be effective in the circumstances described in 208.2, the Department of Building and Housing considers that the requirements of 208.2 impose a requirement higher than that set out in the Compliance Documents of the New Zealand Building Code at the time of publication of this Standard.

(2) This clause is not a requirement for a sprinkler system to comply with the Compliance Documents of the New Zealand Building Code.

208.3

Hose assemblies and associated pipework shall conform to the following:

(a) Hose assemblies installed to comply with 208.2 shall meet the requirements of AS/NZS 1221. A valved gauge connection shall be provided adjacent to the two most hydraulically remote hose reels;

(b) Pipework supplying 25 mm hose reels shall be designed to allow a minimum of 100 L/min to simultaneously discharge from each of the two hydraulically most remote hose reels, with a pressure of at least 450 kPa available at the hose reel valve;

(c) All other installation criteria shall comply with NZS 4503.

NOTE – This clause is not a requirement for a sprinkler system to comply with the Compliance Documents of the New Zealand Building Code.

Extracted from the New Zealand Sprinkler Standard NZS 4541:2007

Figure A4: Provision of Hand Operated Fire Fighting Appliances under NZS 4541:2007

Appendix B

Extracts from Construction Act, Hazardous Substances and New Organisms Regulations, Health & Safety in Employment Act & Maritime Safety Act.

Construction Act 1959 032
Commenced: 1 Apr 1960
Safety Provisions

17 Health and welfare provisions

17\. Health and welfare provisions---(1) Subject to regulations under this Act, every employer shall provide and maintain at places conveniently accessible to workmen employed by him in any construction work adequate and suitable---

(a) Supplies of drinking water;
(b) Accommodation for clothing;
(c) Accommodation for meals;
(d) Sanitary conveniences;
(e) First-aid facilities;
(f) Washing facilities; and
(g) Provision for the drying of clothes.

(2) Subject to regulations under this Act, every employer shall at all times, in respect of any construction work being carried out by him, make adequate and suitable provision for---

(a) Lighting and ventilation;
(b) Safe means of access and egress;
(c) The prevention of fire; and
(d) The dewatering of wet places.

(3) Regulations under this Act may prescribe measures to be taken to ensure compliance with subsections (1) and (2) of this section and may prescribe such other measures to be taken and safeguards to be provided to secure the health and welfare of workmen employed in construction work or of any class of those workmen as may be considered necessary by the Governor-General in Council.

(4) Without limiting the general power contained in subsection (3) of this section, it is hereby declared that regulations may be made under this Act providing, in respect of workmen engaged in construction work, for the supply and use of protective clothing and equipment, the protection of eyes, and the protection from harmful effects arising from such causes as dust, fumes, gases, noise, and shock from explosives.

Extract from the Construction Act 1959 032

Figure B1: Health and Welfare Provisions to be provided by the employer

Construction Act 1959 032
Commenced: 1 Apr 1960
General

30 Regulations

(n) Requiring the provision by employers and the use by workmen of protective clothing, covering, or equipment of a prescribed kind to be used when carrying out construction work generally or specified kinds of construction work:

(o) Requiring the provision of toilets and other sanitary appliances at the site of construction work, and regulating the construction, equipment, control, and use of such toilets and appliances:

(p) Requiring the provision at the site of construction work of supplies of drinking water and facilities for the consumption of meals, and regulating the construction, equipment, control, and use of such facilities:

(q) Prescribing fire-protection precautions to be taken in respect of construction work, requiring compliance with such precautions, and requiring the provision of fire-fighting equipment and materials:

(r) Prescribing the certificates of competency required to be held by safety supervisors and other persons engaged in construction work in any capacity specified in the regulations, and the qualifications and experience required of persons before they are granted such certificates:

(s) Providing for the registration of persons engaged in construction work in any capacity specified in the regulations, prescribing

Extract from the Construction Act 1959 032

Figure B2: Regulations of the Construction Act

Fire Fighting Appliances

40A.55 Fire fighting appliances

(1) The owner and the master of a ship must ensure that fire appliances are provided in accordance with the requirements of Appendix 3 of this Part.

(2) The owner and the master of a ship must ensure that the fire appliances comply with the performance standards prescribed in Part 42B.

(3) The owner and the master of a ship must ensure that the fire appliances are maintained, inspected and serviced in accordance with the requirements of Part 42B.

(4) The master of a ship must ensure that all fire appliances are -

(a) in good working order; and

(b) ready for immediate use;

before the ship commences a voyage, and at all times during the voyage.

Figure B3: Extract from the Maritime rule 40A – Passenger Ships

Fire Fighting Appliances

40C.51 Fire fighting appliances

(1) The owner and the master of a ship must ensure that fire appliances are provided in accordance with the requirements of Appendix 2 of this Part.

(2) The owner and the master of a ship must ensure that the fire appliances meet the performance standards given in Part 42B.

(3) The owner and the master of a ship must ensure that the fire appliances are maintained, inspected and serviced in accordance with the requirements of Part 42B.

(4) The master of a ship must ensure that all fire appliances are in working order and ready for immediate use before the ship commences a voyage and at all times during the voyage.

Figure B4: Extract from the Maritime rule 40C – Non Passenger Ships

7.3 Fire protection

Suitable and sufficient equipment should be provided to ensure people engaged in construction work are protected in the event of fire.

Employers should ensure that:

• Employees are trained to use fire protection equipment;

• Combustible material does not accumulate so as to constitute a fire hazard;

• Sources of ignition are not introduced to any place where combustible materials are stored;

• Storage or handling areas for combustible materials are clearly identified with easily legible lettering "DANGER: NO SMOKING OR NAKED LIGHTS";

• Fire extinguishers are provided in workshops, site offices, main switchboard rooms and in site accommodation. Also, in every place where combustible materials are stored, in every place where welding or flame cutting processes are being carried out, and on every floor of a building or structure.

• Where the construction work includes the installation of a permanent rising water main, the main is installed as the work proceeds as far as practicable so as to be available for use no more than 9 metres below the uppermost working floor;

• Emergency procedures are established for the event of fire. These should include:

- Effective warning systems to facilitate immediate evacuation;

- Clearly defined areas where employers and other persons on site can assemble; and

- A procedure for trial evacuations, at not more than three-monthly intervals.

Extract from the Guidelines for the provision of Facilities and General Safety in the Construction industry

Figure B5: Extract from the Approved Guide for Construction Industry

1.17 Fire precautions

Employers should ensure all places of work comply with the requirements of the New Zealand Fire Service in matters pertaining to fire safety. Such matters will include the number, type and placement of fire fighting devices, alarms and evacuation systems and facilities.

Effective procedures and methods of control are required to minimise the risk of or effect of fire and ensure the safety of all persons in the vicinity.

In workplaces in which there are processes or materials which in the event of a fire are liable to burn with extreme rapidity, emit poisonous fumes or cause explosions, specific control precautions could be required.

Precautions could include the display of safety warning signs, for example those prohibiting smoking or the introduction of naked flames or any other source of ignition into those parts of the place of work.

The employer should ensure that employees are suitably trained in the use and operation of portable or other fire fighting equipment provided at the place of work.

All fire fighting equipment, apparatus and warning signs should be regularly checked and maintained.

Fire and emergency egress exits should be kept clear, be easily identified and always capable of being opened from within.

Emergency procedures should be prominently displayed and practised at least annually.

Such procedures should be regularly reviewed and upgraded or modified as necessary.

Extract from the Guidelines for the provision of Facilities and General Safety in Commercial & Industrial Premises

Figure B6: Extract from the Approved Guide for Commercial and Industrial Premises

New Zealand Government

Department of Labour
TE TARI MAHI

ERMA
New Zealand

Fire and emergency procedures checklist

You must know and understand what to do if a fire occurs. Your first concern is the immediate safety of visitors and staff; secondly, the need to call emergency services and then to contain the fire but only if it is safe to do so. If help is available, allocate responsibilities to others to create a competent fire fighting team.

FIRE EMERGENCY CHECKLIST

1. Raise the alarm and evacuate people from the area
2. Activate the emergency shut down system
3. Call emergency services (dial 111)
4. Call manager

PRECAUTIONS

- Do not endanger yourself – make sure you have an escape route
- Do not use water on petroleum or electrical fires
- Do not leave the site unattended if there is risk of further outbreak
- Advise your manager of the incident

Evacuation point *(Manager to complete)*:

Location of nearest phone *(Manager to complete)*:

FIRE AT A FLAMMABLE STORAGE FACILITY

- Evacuate people from the area
- If it is safe to do so, activate emergency stop and switch off power to all equipment
- If it is safe to do so, close off source of fuel
- Call the fire service (dial 111)
- If a small fire, use your fire extinguisher if it is safe to do so – contain and extinguish the fire
- If a large fire, do not attempt to extinguish the fire – retreat to a safe distance
- If the fire involves LPG, apply water cooling if safe to do so
- Be prepared to direct the fire service to the scene

Figure B7: Extract from a checklist issued by ERMA for Petrol Stations

2.5 Fire Extinguishing Equipment

2.5.1 The type and number of fire extinguishers fitted to the vehicle are to be as per Table 2.1 of this Code.

2.5.2 Fire extinguishers shall be installed so they are:

(a) mounted securely by means of a quick-release attachment

(b) located so as to be readily accessible for use but remote from the hose connection points.

Note. The quick release of a fire extinguisher is deemed to be removal and ready for use within 10 seconds of commencing the release of the extinguisher from the vehicle.

2.5.3 Where two fire extinguishers are fitted to any tank wagon, one is to be located on the left hand side of the road tank wagon, with the other on the right hand side of the vehicle towards the front of the vehicle. If it is not practicable to locate the latter extinguisher towards the front of the vehicle, it is to be located in a position that is still readily accessible by the driver.

Note: For purpose of this clause, an additional towed tank trailer, each additional B-Train tank and similar combination is treated as being an individual vehicle and thus requires an additional complement of extinguishers.

2.5.4 The fire extinguishing medium shall be compatible with the substance being transported.

Table 2.1 – Type and Number of Fire Extinguishers

Application	*Minimum Requirement*
In every vehicle cab	One 30B extinguisher
A road tank vehicle which exceeds 2,000 litres capacity and which carries Class 3.1 A-D Flammable cargo.	2 x 30B or 1 x 60B extinguisher

Figure B8: Extract from Code of Practice for Flammable Liquids Tank Wagons

Appendix C

Fire Extinguisher Use and Training

Fire Extinguisher Use and Training

To optimize effective use of fire extinguishers, personnel should be trained in the use of fire extinguishers. Training of personnel in the use of fire extinguishers is desirable as it helps in controlling a fire in its initial stages and more so in occupancies requiring high degree of life safety such as hospitals, homes for persons with disabilities and welfare centers. It is required by an employer to provide such training to meet their obligations under the Health and Safety in Employment Act.

The Fire Service and specialist training agencies generally recommend that the following procedures should form a guideline for building occupants who discover a fire within their building.

§ Be prepared in advance:

- Know where all the Manual Call Points, escape routes and fire exits are in your building are.
- Familiarise yourself with the location and type of all extinguishers in your building, what types of fires they can be used on, and how to use them.

§ When you discover a fire:

- Remove any casualties or persons requiring assistance in the immediate vicinity to a place of safety (if it is safe for you to do so).
- Assess fire size and decide if first aid fire fighting can be carried out safely.
- Consider containing the fire by turning off heat source, shutting the door, etc.
- Alert building occupants – Using the building fire alarm or shouting 'Fire, Fire, Fire!' and initiate evacuation.
- Contact the Fire Service – get someone else to call 111, stating premises name and address, including town and suburb.
- Select the correct type of extinguisher for the class of fire.
- Ensure another person backs you up with a second extinguisher.
- Approach fire carefully as it may have grown substantially since first noticed, take care opening door to fire room.
- Ensure a safe escape route is available at all times – do not let the fire get between you and your path to safety.
- Operate extinguisher correctly – be prepared to use back up extinguisher.

– Be prepared to evacuate if fire looks like getting out of control.
– Never turn your back on the fire.

§ When deciding if it is safe to fight the fire, consider:

– Size of fire.
– Type and amount of fuel.
– Number of occupants in building and their proximity to you (what if you are alone?).
– Proximity to nearest fire alarm and / or suitable fire extinguisher.
– Location of suitable back up extinguisher.
– Distance to place of safety and ease with which you can evacuate.
– Size of fire on return.

§ Always consider the following:

First aid fire fighting should only be undertaken if it is safe to do so. Anyone making the decision whether to attempt fire fighting, or to evacuate the building, must put their personal safety, and the safety of other occupants, first.

§ Extinguisher Handling

All extinguishers should be clearly labelled with simple operating instructions, and building occupants should be advised to familiarise themselves with the operating instructions before they need to use the extinguisher. Nevertheless, most extinguishers of the same type will operate in a similar manner, and the basic operating methods for common types of extinguishers are listed below.

– Twist and pull to break tie and release pin. Do not grip trigger during this process, as this may prevent pin from coming free.
– All modern extinguishers are designed to work in an upright position.
– Hold handle in one hand, hose (if fitted) in the other, aim away from fire, squeeze trigger to test extinguisher and assess discharge force and throw distance.
– Advance no closer than necessary to the fire, keeping low, upwind if possible and always with the escape route behind you.
– Squeeze trigger, aiming and sweeping nozzle as appropriate for extinguisher type.
– Advance on fire as knockdown occurs, liquid fuel fires must be ‘chased’ until completely extinguished or else flashback will occur.
– When retreating, always face the fire and be aware of flashback, particularly with Class B and F fuels.

- Additional operations specific to extinguisher type.

Water

- Does not generally have an on/off lever, so user must be in position when activating.
- After removing pin, strike top of extinguisher to activate.
- Place finger over nozzle to adjust spray pattern.
- Aim water stream (solid jet) at nearest edge of base of fire, working back, then use spray pattern to dampen down.

Foam

- Ensure nozzle hand does not cover aeration ports.
- Aim away from fire until produced foam is flowing.
- Play foam gently against vertical surface at rear of fire, allowing blanket to roll toward nearest edge of fire, otherwise roll on from nearest edge, or allow to fall on fire as fine droplets by aiming in to the air.

Powder

- Be aware of discharge force.
- Aim nozzle at vapour space between fuel and flames and sweep vigorously from side to side.

Carbon Dioxide

- Be aware of discharge force.
- Do not grasp horn in hand due to extreme cold.
- Sweep extinguisher from side to side at medium speed to lay CO_2 on to fire so as to displace the oxygen.
- Do not touch metal surfaces in path of medium due to extreme cold.
- Be aware of possible static charge from horn.
- Be aware of asphyxiation danger in confined space and limited effectiveness outdoors due to wind.

Appendix D

Fire Extinguisher Usage Survey 2008 – Information Pack

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

FPA NEW ZEALAND

Department of Civil Engineering
University of Canterbury,
Private Bag 4800,
Christchurch, New Zealand.

2a Rothwell Ave, Albany, Auckland
Private Box 302-372, North Harbour 1330
Ph (09) 414 4450 • Fax (09) 414 5707
Email: fpanz@fireprotection.org.nz

May 6, 2008

Dear Fire Protection Industry Member

Re: Fire Protection Industry Survey on the Use of Fire Extinguishers by Building Occupants

The University of Canterbury and the Fire Protection Association of New Zealand are conducting a study assessing the cost benefits of Hand Operated Fire Fighting Equipment (HOFFE) installations in Buildings in New Zealand. This study is in continuation of a previous survey piloted by the New Zealand Fire Service in 2001 as a part of the process of producing a new Code of Practice for Hand Operated Fire Extinguishers. This survey is being done as a research project by a Masters Student from the University.

This research is vital in bringing in information about the use of HOFFE by building occupants in actual fire situations. A similar research in the UK & Europe has shown significant benefits due to the use of HOFFE in terms of fire saves achieved and overall annual savings in the operational costs of the Fire Services organizations. This research will provide significant inputs in the development of a Code of Practice for Hand Operated Fire Extinguishers. One of the best sources to provide this sort of information are the members of the fire protection industry.

Because the data collected will be used to compare with a risk based model designed to provide a cost benefit analysis it will be used as an integral part of the new code of practice and thus will play an important role in the future of the fire protection industry. We are therefore appealing to all members of the fire protection industry to put in the small amount of time and effort that is necessary to ensure that this survey is a success.

Please find attached a copy of the Fire Protection Industry Survey Forms. We have 3 different forms that need to be filled out. A brief description is provide below

FES 01 is a extinguisher & hose reel data sheet that will be used to compile statistical information regarding installed capacity and costs across the country. This form will require to be filled once every month,

FES 02 is a form is to be used by your field technician / engineers on site to record fire extinguisher usage. This for is to be filled for recording each use,

FES 03 is a form that records incidence of extinguisher use and is similar to the one used by the Fire Service in the last survey. This form needs to be filled once during the survey.

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
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Please photocopy the survey forms before using it, and keep a number of spare copies with you. On the forms a guide is provided to assist you in filling out the form accurately. The forms have been modified and redeveloped based on feedback from the industry from the previous surveys. We have tried to keep the format simple and easy to use. In addition to the data fields required in the previous survey we have requested additional information to understand the installed capacity & distribution of HOFFE in different occupancies in New Zealand. This information will be used mainly to create statistical information for New Zealand. All data received will be treated as confidential and will be released as statistical figures only.

Please start using the survey form as soon as you receive it, and send in the completed form to the fax number provided at the top of the survey form at the end of each month (or as each page is filled up).

For the information to have any credibility, the survey needs to run for a minimum of three months. The ideal time frame to get a true picture of extinguisher use in New Zealand is one year. We will provide you with monthly updates to let you know how the survey is going and if it will be run for more than 3 months.

We cannot stress enough how important this survey will be to ensure a meaningful conclusion of the research project and to further development of the code of practice. In addition, the data gathered will be very useful to the fire protection industry itself and to you as members of that industry.

We believe that the survey form is quick and easy to fill out, and should provide minimum disruption to your routine. The results of everyone getting behind the survey and approaching it in a professional manner will be tremendously beneficial to all of us.

Yours faithfully

Biswadeep Ghosh
Fire Engineer
Beca Carter Hollings & Ferner Ltd
(Student – MEFE University of Canterbury)

Bob Taylor
Executive Director
Fire Protection Association NZ

College of Engineering

Michael Spearpoint
Department of Civil and Natural Resources Engineering
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UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

3rd June 2008

Dear Sir/Madam,

USE OF HAND-HELD FIRE EXTINGUISHERS IN BUILDINGS

Biswadeep Ghosh currently working on his Masters degree in Fire Engineering at the University of Canterbury. As part of his project he is looking to gather information regarding the use of hand held fire extinguishers. The data are being collected purely for statistical reasons. Although forms are to be returned to the FPANZ fax number they will not to be retained or used by the FPANZ. Individual companies and commercial information will not be identified in the research and if you request, the forms can be destroyed once the project has been completed. Should you have any concerns or comments about this project, please contact me at the University of Canterbury at michael.spearpoint@canterbury.ac.nz.

Yours sincerely

M Spt

Dr Michael Spearpoint
New Zealand Fire Service Commission Lecturer in Fire Engineering

FES 01

FPA NEW ZEALAND

UC UNIVERSITY OF CANTERBURY

FIRE PROTECTION INDUSTRY EXTINGUISHER SURVEY FORM

Fax completed form to: (09) 4145707 or post to: Extinguisher Survey, FPANZ, Private Box 302-372, North Harbour 1330

Company:____________________________

Region:____________________________

Service Person:________________________

Number of Extinguishers serviced			Nos.		Service Information			
Number of Hose Reels serviced			Nos.		A	Average cost to install an extinguisher	NZ$	
Distribution of serviced extinguishers					B	Average cost to install a hose reel unit	NZ$	
1	Residential		Nos.		C	Average Maintenance cost per unit	NZ$	
2	Commercial		Nos.		D	Average refilling cost per unit	NZ$	
3	Industrial		Nos.		E	Average pressure testing cost per unit	NZ$	
4	Warehouse		Nos.		F	Average extinguisher training costs	NZ$	
5	Retail		Nos.					
6	Vehicle/Boat/Caravan		Nos.					
7	Others		Nos.					

1. This information is being collected to generate statistical data of extinguisher installation within New Zealand. This information will be presented statistically in the final form without references to service company.
2. Please note that as the information provided in this survey might be deemed commercially sensitive, all replies will be treated in the strictest confidence.
3. Average costs can be a weighted average, as we understand that installation & maintenance costs will vary with the size of the install and relationship with the client. Please include costs after required margins are included
4. Extinguisher training means training service provided to the client for the purpose of using the extinguishers. If the service company does not provide training please mark as N/A

IMPORTANT: PHOTOCOPY THIS PAGE BEFORE USING!

FPA NEW ZEALAND

FIRE PROTECTION INDUSTRY EXTINGUISHER SURVEY FORM

FES 02

Fax completed form to: (09) 4145707 or post to: Extinguisher Survey, FPANZ, Private Box 302-372, North Harbour 1330

UC UNIVERSITY OF CANTERBURY

Company: ______________________ Date: ____________

Region: ______________________ Site ID: ____________

Service Person: ______________________

Building Type

Residential	☐	Warehouse	☐	Boat	☐
Commercial	☐	Retail	☐	Caravan	☐
Industrial	☐	Vehicle	☐	Other	☐

Class of Fire

A = Normal Combustibles	☐	D = Metals	☐
B = Flammable Liquids	☐	E = Electrical	☐
C = Flammable Gases	☐	F = Cooking Fats and Oils	☐

Type of Extinguisher Used

Water	☐	Wet Chemical	☐
CO2	☐	Foam	☐
Dry Powder	☐	Vaporizing Liquid	☐

Number & Capacity of Extinguishers used (*liters / kg + number*)

Water	_____	Wet Chemical	_____
CO2	_____	Foam	_____
Dry Powder	_____	Vaporizing Liquid	_____

Extinguisher Effectiveness

Fire Extinguished	☐	Not Extinguished	☐
Fire Partially Extinguished	☐	Fire too Large	☐
Fire Re-Ignited	☐	Extinguisher not Suitable	☐

Extinguisher Used By

Building owner / occupier	☐	Passerby / others	☐
Fire Service personnel	☐		

Was the Fire Brigade Called? **Yes** ☐ **No** ☐

Were Hose Reels used?	**Yes**	☐	**No**	☐	**N/A**	☐
Sprinkler activation?	**Yes**	☐	**No**	☐	**N/A**	☐

Estimated Losses ________ **NZ$**

Any other Information

____

____

Please note that as the information provided in this survey might be deemed commercially sensitive, all replies will be treated in the strictest confidence.

! IMPORTANT: PHOTOCOPY THIS PAGE BEFORE USING

NEW ZEALAND

UNIVERSITY OF CANTERBURY

INDUSTRY SURVEY ON THE INCIDENCE OF FIRE EXTINGUISHER USE

The University of Canterbury in association with Fire Protection Association with New Zealand is conducting a research project to assess benefits of Hand Held Fire Fighting Equipment (HOFFE) and its usage in New Zealand to fight fires. In order to assist with this process, answers to the following questions would be greatly appreciated. Please note that as the information provided in this survey might be deemed commercially sensitive, all replies will be treated in the strictest confidence.

In order to validate the information being supplied, we would grateful if you could you supply a contact name and phone number, which will also be treated in the strictest confidence. Please feel free to supply any additional, or even incomplete, information that may assist us in developing an effective code of practice.

Name: ______________________________ Phone: ______________________

Company: ___________________________ RETURN FAX: **(09) 4145707**

(or post to: Extinguisher Survey, FPANZ, Private Box 302-372, North Harbour 1330)

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1. Recharges

Can you provide us with the number of recharges that your company has carried out per annum, preferably over the past 5 years?

---

2. Number of recharges resulting from use on fires

Allowing for extinguishers discharged during training sessions, scheduled maintenance, and by accident, are you able to give an indication of the number of recharges that resulted from use on an actual fire?

---

3. Training sessions

Can you provide us with the number of training sessions your company has carried out per annum on the use of fire extinguishers, preferably over the past 5 years?

---

4. Number of persons trained

Can you give an indication of the average number of people who attend a training session?

---

5. Refresher training

Are you able to indicate how many of the training sessions are refresher training for persons who have already been provided with extinguisher training?

IMPORTANT: PHOTOCOPY THIS PAGE BEFORE USING

Appendix E

Understanding Fire as a Risk

Understanding Fire as a Risk

Fire can be good or bad, useful or threatening, absolutely essential but potentially lethal depending on the situation it is used in. If it is controlled it is beneficial and sometimes essential, if it is uncontrolled it can cause fatalities, destroy property and interrupt businesses.

What is burning?

The burning process is a continuous chemical reaction between oxygen and fuel that have heated up to ignition temperatures. This represents the triangle of fire. When you remove any one component the fire goes out. Burning occurs when a fuel combusts and gives off enough heat to keep the burning going. Nearly 21% of the air is oxygen so there is generally enough for a fire to burn. Sometimes other substances can act as oxidizers and therefore materials that burn freely in air can burn violently in the presence of oxidizers. Fires can be slow, without flames – smouldering, or fast and explosive. In between we have flaming fires. Fuels come in different forms, solids (wood, coal, paper etc), liquids (petroleum products, alcohols etc) and gases (propane, methane etc). Most of the burning happens when there is sufficient heat produced so that solid and liquid fuels generate vapour that mixes with air and combusts, gases mix easily with oxygen and thus burn freely.

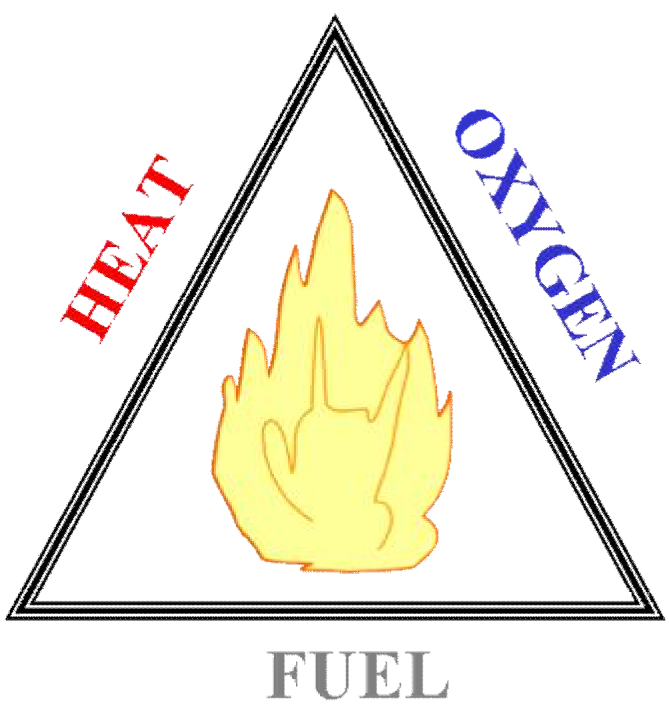


Figure 1: The Fire Triangle

Ignition Sources

Fires start when an ignition source containing enough energy heats up a fuel to its piloted or auto-ignition temperature. The amount of energy required depends on the fuel size and its packing configuration. Most of the time it is the ignition source that starts a fire since fuel and air are normally available together under most circumstances. One of the key concepts in fire prevention is to remove the ignition source. The following table summarizes some of the main ignition sources in New Zealand and overseas.

Ignition Source	Percentage
Arson	40%
Failure or improper use of electrical equipment or electrical wiring systems that are overloaded	15%
Carelessly discarded lighted cigarette materials	15%
Hot work operations (welding and cutting) and failure to follow hot work permit procedures	15%
Other causes including: - Chemical reactions - spontaneous ignition or self heating - friction (when mechanical equipment is poorly lubricated or maintained) - external fires (sparks or radiated heat) - static electricity	15%

extract from SNZ HB 4525 – Fire Risk Management Handbook

Table 1: Ignition Sources

Fuels

For a fire to start, the fuel must be in the right form. For example, it is relatively difficult to set wood on fire when it is in the form of newly felled tree trunk. After drying and cutting into smaller pieces of wood, it is easier to set on fire. If the wood is converted to paper, it can easily be set on fire. Wood dust in air can be explosive.

Fuels are in available as a solid, liquid or in gaseous form. Sometimes fuels are in different forms based on how they are stored or at different temperatures and can offer challenges. Example LPG is a liquid when it is cold and stored in a cylinder, as it warms up it boils and forms an invisible vapour. LPG being heavier than air it floats at ground level and is able to channel into drains etc.

Oxygen

Oxygen is present in air at a mix ratio of 21%. This ratio decreases as we move to higher altitude. Oxygen can also be stored and used for controlled fires, like Oxy-acetylene torches etc. Therefore, oxygen leaks can enhance the burning process and make fuels burn violently.

Breaking the Fire Triangle

Removing or reducing one of the sides of fire will cause the fire to slow and finally go out. Extinguishing systems are based on this principle. Prevention of fires also can be achieved if we remove one of the sides of the fire triangle. The fire triangle can be broken by the following processes:

- § Removing the ignition source or removing heat – Lack of an ignition source Oxygen is present in air at a mix ratio of 21%. This ratio decreases as we move to higher altitude. Cooling the fire so that there is insufficient heat to continue burning. Extinguishing agents like water, CO2 etc help in cooling the fire thus reducing the burning process till it stops.
- § Remove the oxygen source – Fire cannot continue burning without oxygen, therefore a lack of oxygen will smother the fire. Smothering agents such as foam or dry powder starve the fire of oxygen thus putting it out. CO2 extinguishers evacuate oxygen from the immediate region of fire thus the fire is unable to sustain.
- § Remove the fuel – Burning does not happen if there is no fuel to burn. If we can remove the fuel from a source of heat we can prevent a fire from stating, if a fire is burning, if we are able to reduce the fuel or apply agents that stop the chemical reaction, the burning process is interrupted.

If we are able to keep one side of the triangle away from the other sides a fire cannot start, in practical terms keeping the heat/ignition source away from fuels is the easiest.

How do fires start?

All fires start with an ignition source that is either new or no longer contained. For ignition to occur, all the following conditions must exist simultaneously and be continuous.

- Sufficient heat must be present to provide the required energy for the chemical reaction to start. Energy to cause ignition will vary with different fuels. The energy to cause ignition may be in the form of a match strike, spark, cigarette or open flame;
- There has to be enough fuel vapour in the air; not too much, not too little; and
- There has to be sufficient oxygen to burn.

Once a fire has started it is a self sustaining heat engine. A fire is the combustion of vaporized fuel, which when burnt produces heat, which in turn converts more fuel into vapour, thus continuing the combustion cycle. The speed with which a fire grows will depend upon what is available to burn and how it is arranged. Some fuels can quickly spread fires while others burn locally.

How fast do fires grow?

The rate of fire growth depends on the fuel that is burning, and how much air can get to the fire. Fires in liquids and gases grow very fast but some solid materials also burn easily. Thin materials like cardboard burn faster than thick materials like timber. The arrangement of the fuel also determines fire growth and spread. The amount of fuel available per square area determines the fire load, a high fire load can result in a very large fire.

How does heat move around?

The usefulness or destruction from a fire results from the movement of heat away from the flame into the adjacent area. Heat is generally transferred in the following three modes:

1. Convection – transfer of heat by moving particles or liquids or gases, like the heat that flows out of a kettle in a flow of steam,

2. Conduction – transfer of heat through a solid, like heat that we feen when we touch a hot stove body,

3. Radiation – transfer of heat by infrared electromagnetic radiation, heat that we feel from a heater in a room.

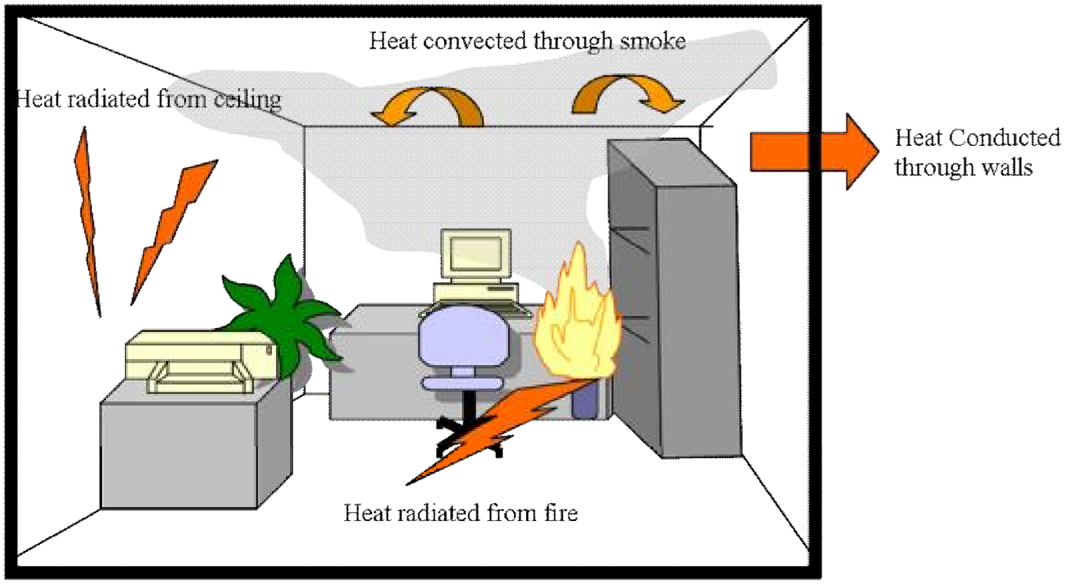


Figure 2: Modes of Heat Transfer

What is smoke and how does it spread?

Smoke from fires is a hot product of combustion. It essentially comprises of water vapour, carbon dioxide, carbon monoxide, un-burnt carbon, combustion vapours and other gaseous by products depending on the fuel that is burning. Smoke generated during a fire is a hindrance to escape and can be fatal.

Because smoke is usually much hotter than the surrounding air it has buoyancy and can move through openings and doors to the top of a building and gradually fill it. Generally smoke rises upwards and then descends down till it spills out of the room. All the time the heat from the smoke is warming the building and its contents. Eventually, other parts of the building, remote from the original fire, can ignite by the heat from the smoke. Smoke is also dangerous as it can spread to different parts of a building via ceiling voids, service ducts, lift shafts etc.

Generally smoke endangers life in a fire situation because:
- it reduces visibility including light illumination,
- contains poisonous gases,
- is capable of transferring heat and thus fire spread,
- contains unburned flammable gases that can ignite suddenly.

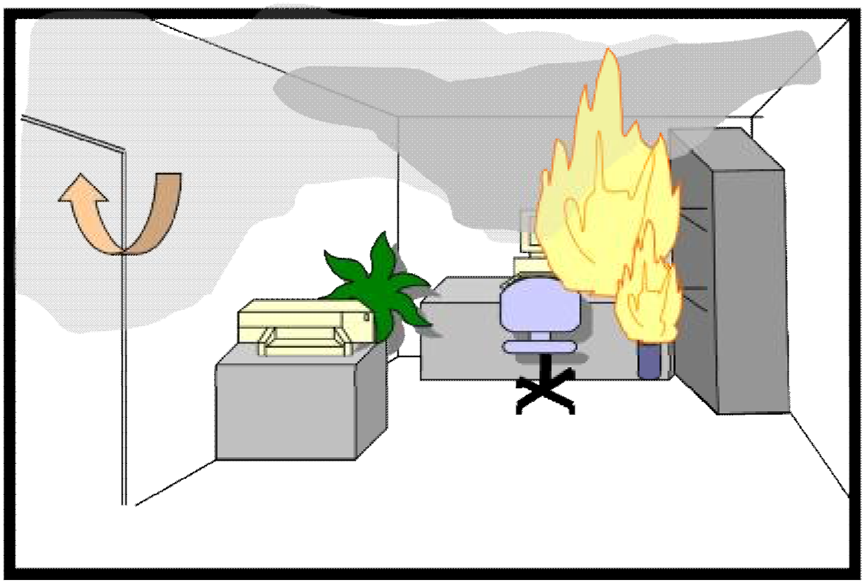


Figure 3: Smoke Spread in a room

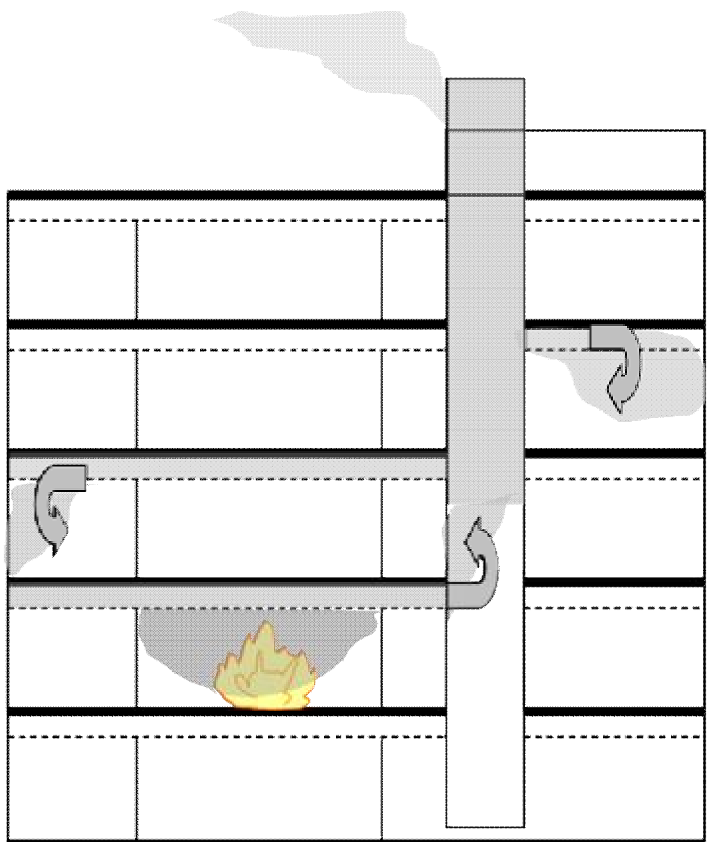


Figure 4: Smoke Spread in a building

How does fire develop in a room?

Fires burn fast especially in an enclosed space. This is mainly because smoke from a fire radiates heat back to the room, thus creating sufficient heat to increase the temperature in the room which starts to increase vaporization of fuels thus creating conditions for other fuel packages to ignite.

If a room has inadequate ventilation it causes the fire to slowly burn out, however there may be sufficient hot combustible vapours that could explode if a door or window opened suddenly. This is generally known as a back draft and it has disastrous consequences. When a room has adequate ventilation the fire tends to burn with an exchange of fresh air and smoke, air entering at lower level and entraining into the smoke plume. The smoke layer descends as the fire burns hotter. At this stage there is sufficient heat in the room to spontaneously ignite other combustibles in the room thus involving the entire room, this is termed as flashover. At this stage hot gases flow out of the compartment of fire origin into the neighbouring compartments thus causing fire to spread rapidly. Flashover occurs generally when the compartment temperature reaches around 600 deg C. At this time the fire continues burns out of control till all fuel is consumed or fire fighters intervene.

The various stages of fire are

1. Ignition
2. Incipient / smouldering
3. Growth
4. Steady state
5. Decay

These stages are indicated in the figure below.

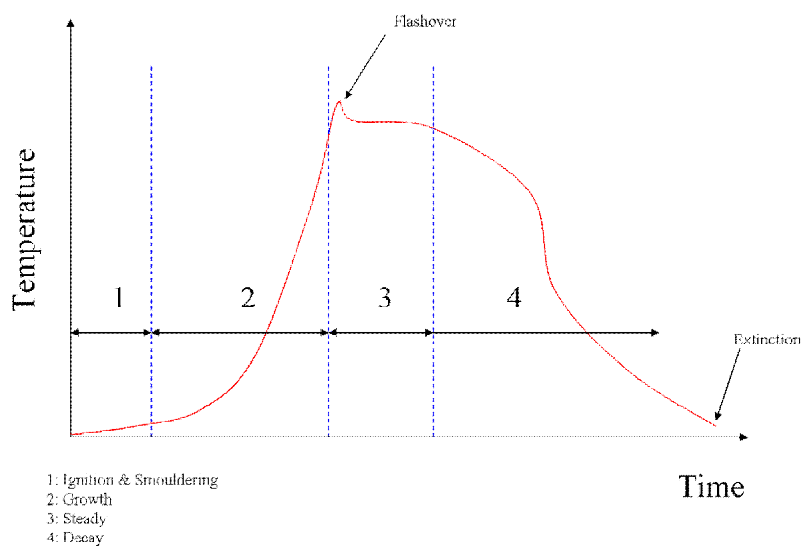


Figure 5: Stages of Fire Development

How can fires be detected and controlled?

Fires can grow fast and become deadly, it is important that we detect them early, preferably with an automatic system. Detection of fires is based on early identification of combustion products. Detectors may be designed to detect smoke, heat, CO2, obscuration (beam detectors) or multi criteria. The essential principle is to provide an early warning to occupants before a fire becomes fully developed.

Detection systems are combined with alarm systems that provide audible (sounders) or visual (strobes / warning lights) indications to occupants and initiates evacuation. Alarms are also connected to the Fire Service receiving equipment that alerts the Fire Department of the building, area and type of alarm. This is essential since certain buildings may require staged evacuation or assistance during evacuation (hospitals, secure facilities etc.) It also ensures that a fire incident is monitored after-hours when the building may not be occupied. Most of the detection and alarm systems in New Zealand are designed and installed to comply with NZS 4512.

Most detection systems are designed for life safety, however automatic suppression systems are also provided in buildings to fight fires, contain them to aid evacuation and for property protection. Sprinklers, gas suppression, foam suppression are some of the automatic systems available to fight fires. Other than these buildings are equipped with hydrant risers to assist the Fire Service to fight fires. Most automatic fire suppression systems are also interface with the alarm system to alert occupants and the Fire Service if a system has activated.

Apart from automatic systems, manual detection by sight and smell is also another way of raising alarm. Occupants discovering a fire can raise alarm by operating a manual call point if their building is installed with one or by verbal communication using phones, PA systems etc. Successful evacuation using manual detection however is dependant on the size of fire when it is discovered. Similar to detection manual intervention of a fire in its incipient stage using portable fire fighting equipment can result is a fire save, which in turn can have lower cost impacts resulting from a fire incident.

Appendix F

Risk Simulation Models

Simulation Model 1

Building Type - Residential

Risk Input Data

Building Data

Floor area	100	202	250	193	m^2	
Assumed height	3.5	5	7	5.08	m	
Average building cost	1450	1638	1825	1637.83	$\$/m^2$	

Cost benefit parameters

Analysis period				50	Years	
Discount rate				8	%	
inflation rate				3	%	
Real Discount Rate				5	%	
life of building				50	Years	
life of fire protection system				50	Years	

Fire Protection Systems reliability & effectiveness

Probability of detection success (manual)	0.1	0.2	0.3	0.20		
Probability of detection success (Automatic)	0.68	0.84	0.9	0.82		
Probability of manual suppression success /fire detected	0.2	0.4	0.8	0.43		
Probability of automatic sprinkler suppression	0.6	0.8	0.9	0.78		
Probability of fire barrier success	0.4	0.65	0.9	0.65		

Fire initiating likelihood	0.003	0.004	0.0045	0.0039	fires/year/household	

Fire Protection System costs

Fire Alarm fixed cost				150	\$/building	
Fire alarm variable cost				0	$\$/m^2$	
Extinguisher cost / unit	190	220	280	225.00	\$/unit	
Number of extinguishers for this model				1	units	
Extinguisher maintenance	59	65	80	66.50	\$/year	
Extinguisher training cost				0	\$/year	
Sprinkler system installation cost	20	25	35	25.83	$\$/m^2$	
Sprinkler system maintenance cost				100	\$/year	
Fire service connection cost				0	\$/year	
Fire wall costs				0	$\$/m^2$	
Fire protection installation costs per m^2 (manual detec & supp)				1	$\$/m^2$	
Fire protection installation costs per m^2 (auto detec & supp)				2	$\$/m^2$	
Fire protection installation costs per m^2 (with sprinklers)				28	$\$/m^2$	
Fire protection installation costs per year over lifetime		5	8	111	\$/year	
Average fire protection costs		71	74	278	\$/year/household	

Fire Loss Area

No systems				38.02	m^2	39
With detection & manual suppression		0	3	1.5	m^2	
with sprinklers		3	20	11.5	m^2	38.021
with fire wall effectiveness				0	m^2	

Fire Loss costs

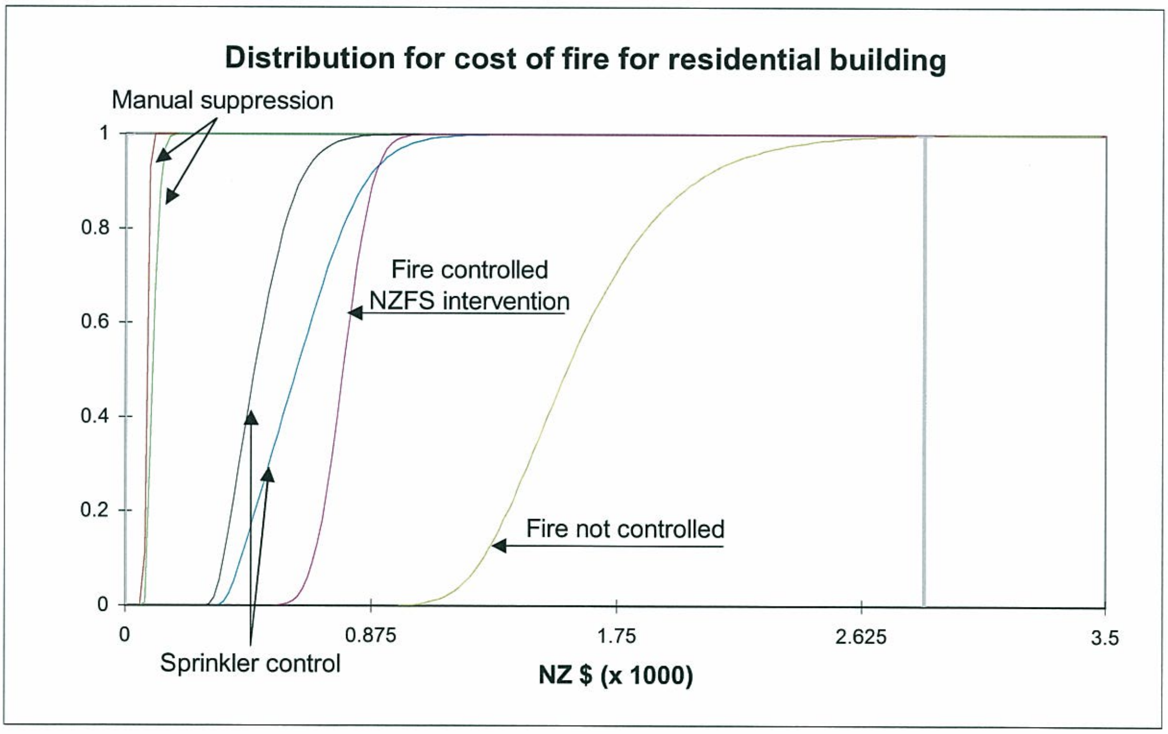
Property Losses		16605	1660.5	16605	\$/fire	
fire service costs		5875	587.5	5875	\$/fire	
Total costs				22480	\$/fire	

@RISK Correlation Sheet

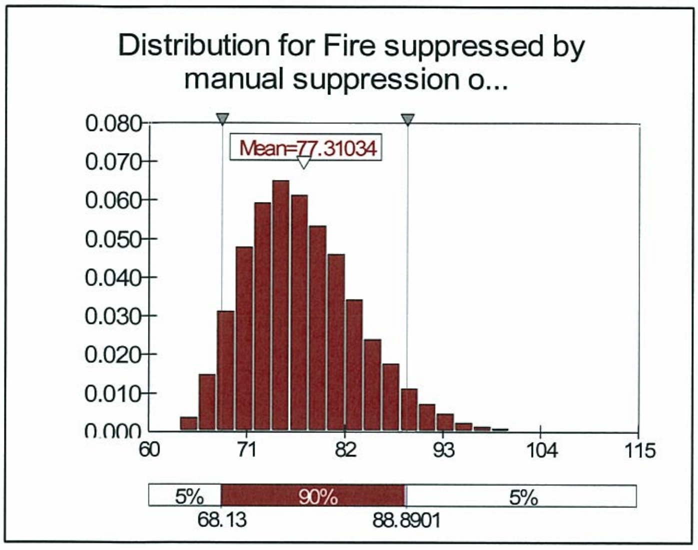
NewMatrix1 (4x4)	Sheet1!G34 Extinguisher cost / unit	Sheet1!G36 Extinguisher maintenance	Sheet1!G38 Sprinkler system installation cost	Sheet1!G10 Floor area
Sheet1!G34 Extinguisher cost / unit	1			
Sheet1!G36 Extinguisher maintenance	0	1		
Sheet1!G38 Sprinkler system installation cost	0	0	1	
Sheet1!G10 Floor area	0.4	-0.4	-0.5	1

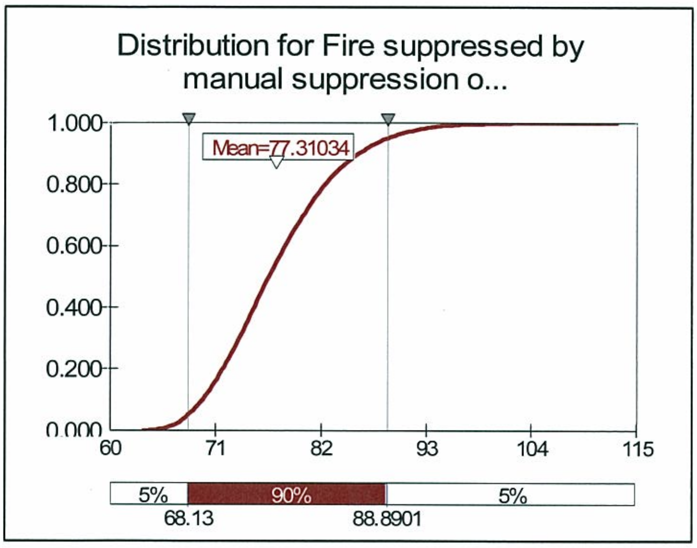
Simulation 1 results table

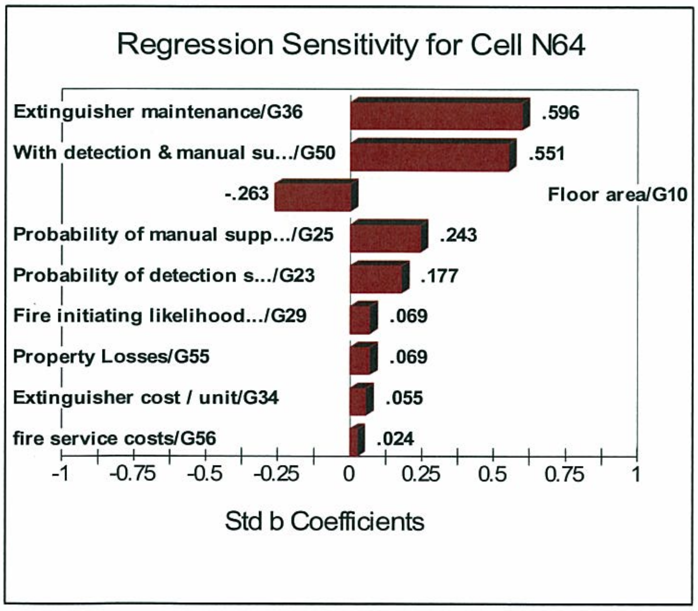
Scenario	Total cost of fire per year per household		
	Mean	Standard deviation	Upper 95th percentile & rank
No fire protection - complete loss	1620	306	2195(7)
No fire protection - Fire service intervention (80% damage)	775	81	910(6)
Manual suppression following manual detection	77	6	89(1)
Manual suppression following automatic detection	99	18	134(2)
Sprinkler suppression following failure of manual suppression	474	107	673(3)
Sprinkler suppression no manual suppression applied	624	171	927(4)



Simulation Results for
Fire suppressed by manual suppression on manual detection / of fire / N64







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Number of Simulations	1
Number of Iterations	25000
Number of Inputs	17
Number of Outputs	6
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 12:40
Simulation Stop Time	29/09/2008 12:41
Simulation Duration	00:01:23
Random Seed	1005917417

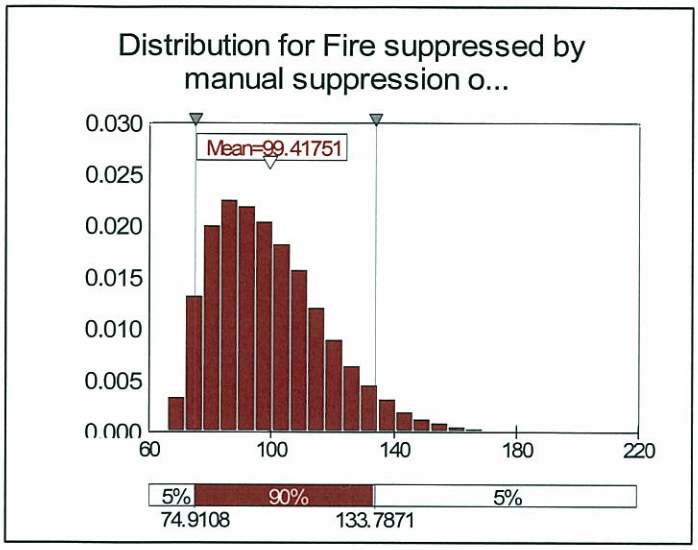
Summary Statistics

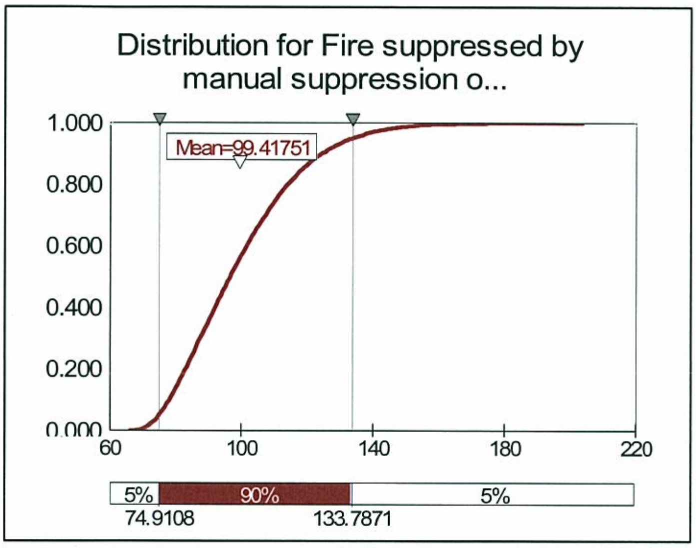
Statistic	Value	%tile	Value
Minimum	64	5%	68
Maximum	113	10%	70
Mean	77	15%	71
Std Dev	6	20%	72
Variance	40.56650737	25%	73
Skewness	0.64706167	30%	73
Kurtosis	3.494012235	35%	74
Median	77	40%	75
Mode	71	45%	76
Left X	68	50%	77
Left P	5%	55%	77
Right X	89	60%	78
Right P	95%	65%	79
Diff X	21	70%	80
Diff P	90%	75%	81
#Errors	0	80%	82
Filter Min		85%	84
Filter Max		90%	86
#Filtered	0	95%	89

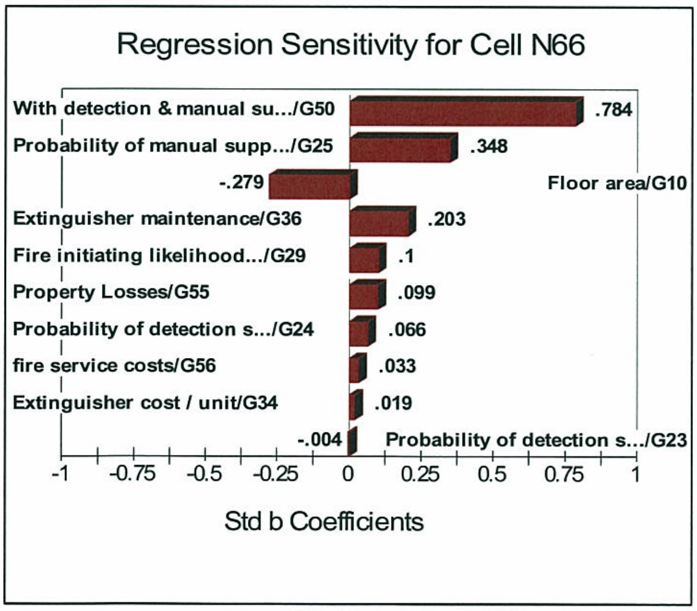
Sensitivity

Rank	Name	Regr	Corr
#1	Extinguisher mai	0.596	0.713
#2	With detection &	0.551	0.557
#3	Floor area / G	-0.263	-0.464
#4	Probability of ma	0.243	0.220
#5	Probability of det	0.177	0.160
#6	Fire initiating like	0.069	0.056
#7	Property Losses	0.069	0.055
#8	Extinguisher cos	0.055	-0.037
#9	fire service costs	0.024	0.021
#10	Assumed height	0.000	0.006
#11	Average building	0.000	-0.004
#12	Probability of det	0.000	0.005
#13	Probability of aut	0.000	-0.002
#14	Probability of fire	0.000	-0.006
#15	Sprinkler system	0.000	0.124
#16	with sprinklers /	0.000	0.001

Simulation Results for
Fire suppressed by manual suppression on automatic detection / of fire / N66







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Simulation Stop Time	29/09/2008 12:41
Simulation Duration	00:01:23
Random Seed	1005917417

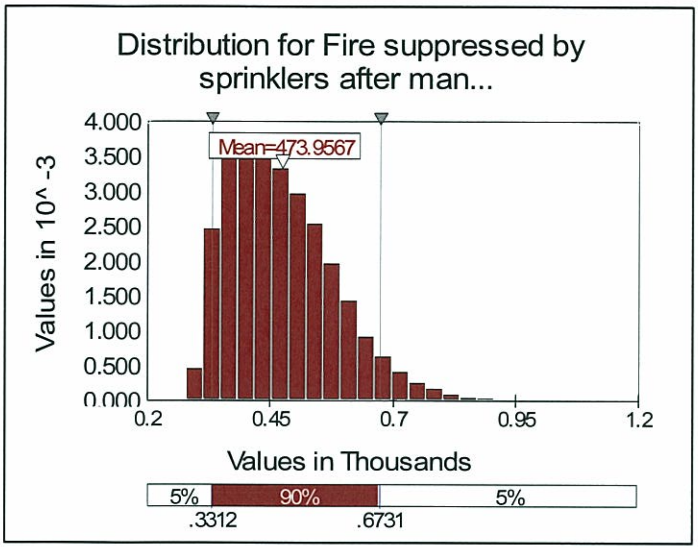
Summary Statistics

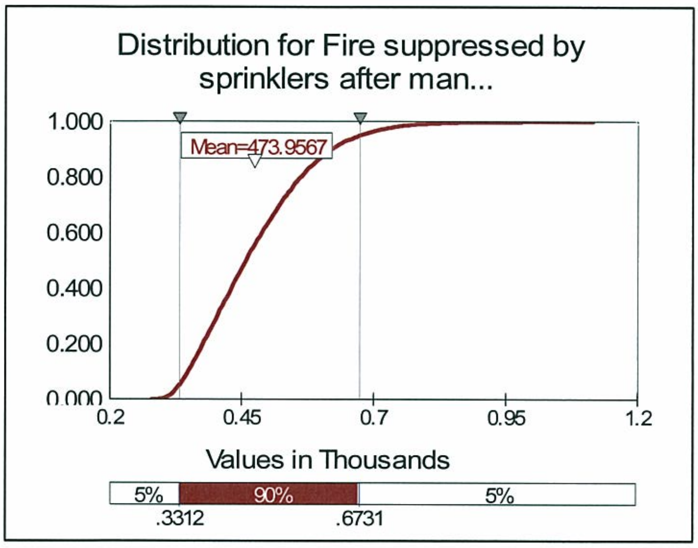
Statistic	Value	%tile	Value
Minimum	66	5%	75
Maximum	204	10%	78
Mean	99	15%	81
Std Dev	18	20%	83
Variance	339.6892525	25%	85
Skewness	0.836934796	30%	87
Kurtosis	3.742886259	35%	90
Median	97	40%	92
Mode	92	45%	94
Left X	75	50%	97
Left P	5%	55%	99
Right X	134	60%	102
Right P	95%	65%	104
Diff X	59	70%	107
Diff P	90%	75%	110
#Errors	0	80%	114
Filter Min		85%	119
Filter Max		90%	125
#Filtered	0	95%	134

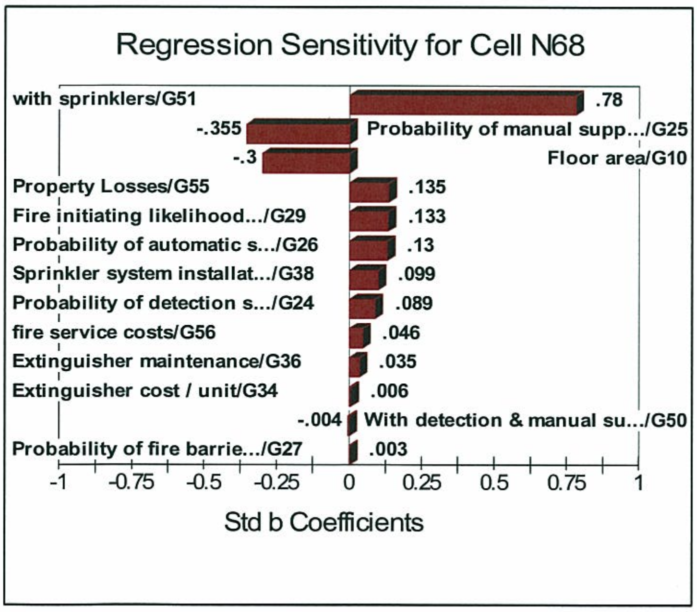
Sensitivity

Rank	Name	Regr	Corr
#1	With detection &	0.784	0.835
#2	Probability of ma	0.348	0.308
#3	Floor area / G	-0.279	-0.318
#4	Extinguisher mai	0.203	0.313
#5	Fire initiating like	0.100	0.078
#6	Property Losses	0.099	0.083
#7	Probability of det	0.066	0.064
#8	fire service costs	0.033	0.032
#9	Extinguisher cos	0.019	-0.069
#10	Probability of det	-0.004	-0.007
#11	Assumed height	0.000	0.006
#12	Average building	0.000	-0.003
#13	Probability of aut	0.000	-0.003
#14	Probability of fire	0.000	0.003
#15	Sprinkler system	0.000	0.125
#16	with sprinklers / $	0.000	0.001

Simulation Results for
Fire suppressed by sprinklers after manual suppression failed / of fire / N68







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Simulation Duration	00:01:23
Random Seed	1005917417

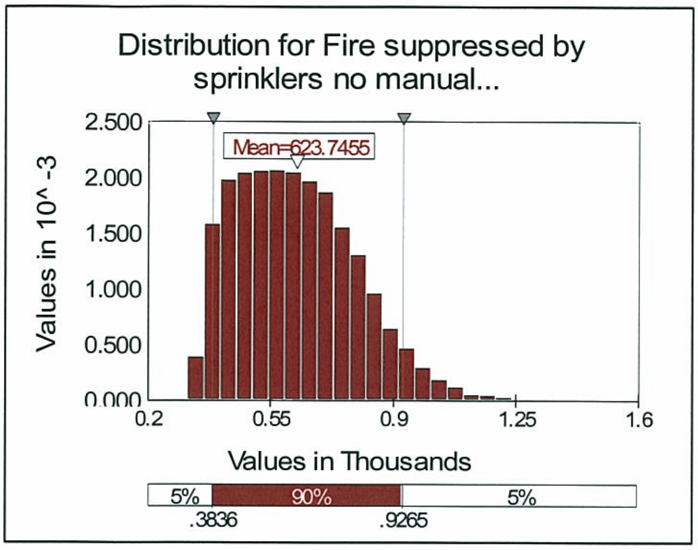
Summary Statistics

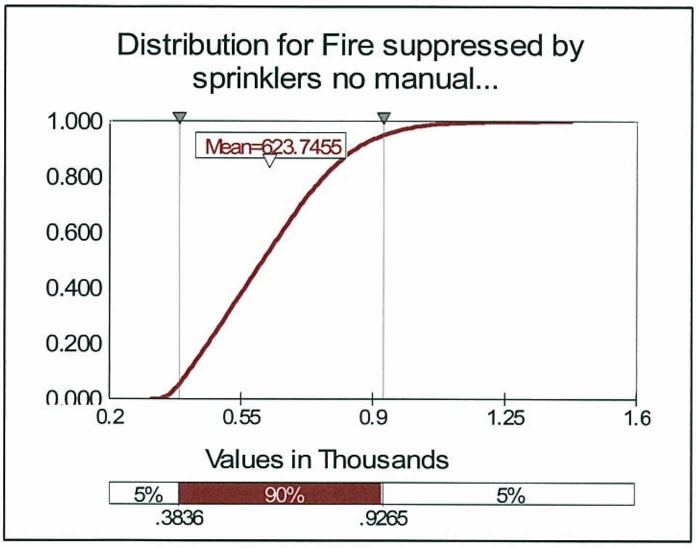
Statistic	Value	%tile	Value
Minimum	279	5%	331
Maximum	1115	10%	349
Mean	474	15%	363
Std Dev	107	20%	376
Variance	11532.5499	25%	390
Skewness	0.806124	30%	404
Kurtosis	3.619881609	35%	417
Median	458	40%	430
Mode	405	45%	444
Left X	331	50%	458
Left P	5%	55%	473
Right X	673	60%	488
Right P	95%	65%	504
Diff X	342	70%	522
Diff P	90%	75%	541
#Errors	0	80%	562
Filter Min		85%	587
Filter Max		90%	619
#Filtered	0	95%	673

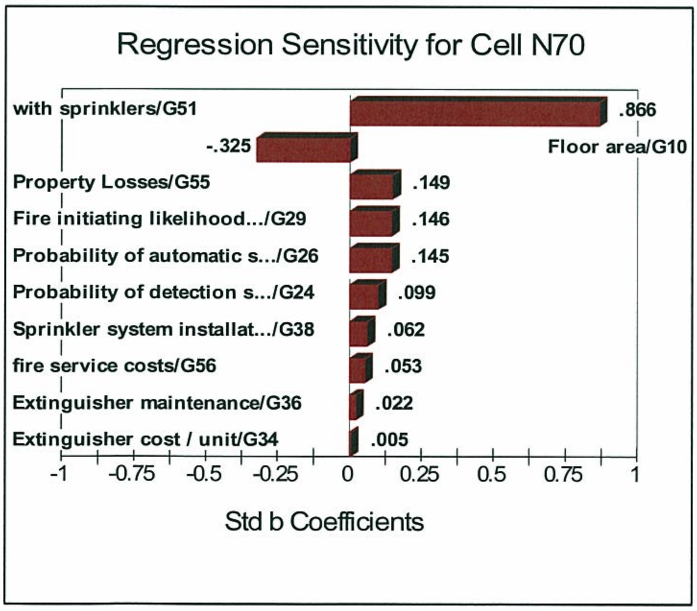
Sensitivity

Rank	Name	Regr	Corr
#1	with sprinklers / $	0.780	0.826
#2	Probability of ma	-0.355	-0.339
#3	Floor area / G	-0.300	-0.320
#4	Property Losses	0.135	0.117
#5	Fire initiating like	0.133	0.124
#6	Probability of aut	0.130	0.116
#7	Sprinkler system	0.099	0.230
#8	Probability of det	0.089	0.062
#9	fire service costs	0.046	0.037
#10	Extinguisher mai	0.035	0.142
#11	Extinguisher cos	0.006	-0.100
#12	With detection &	-0.004	0.004
#13	Probability of fire	0.003	-0.005
#14	Assumed height	0.000	-0.002
#15	Average building	0.000	0.002
#16	Probability of det	0.000	-0.004

Simulation Results for
Fire suppressed by sprinklers no manual intervention / of fire / N70







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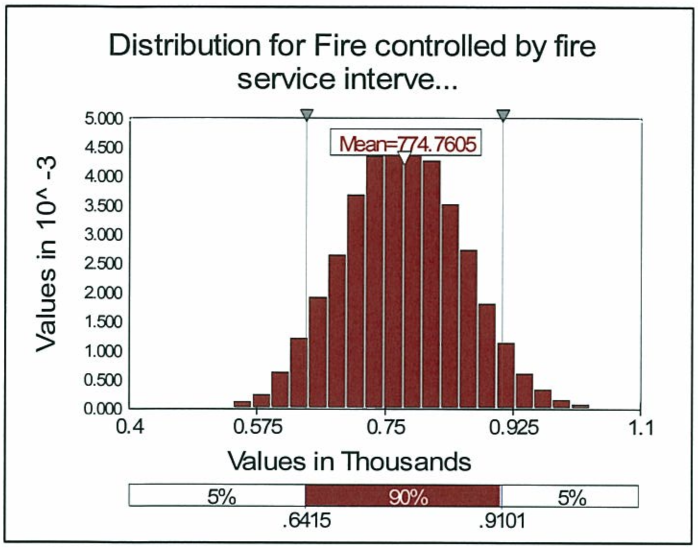
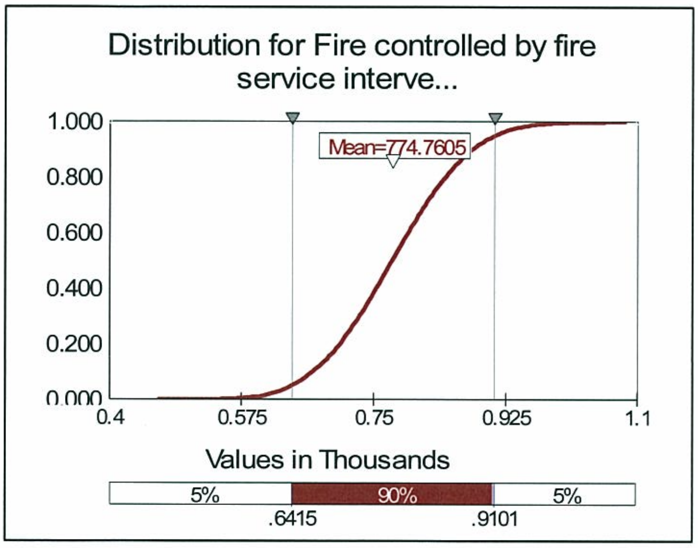
Random Seed	1005917417

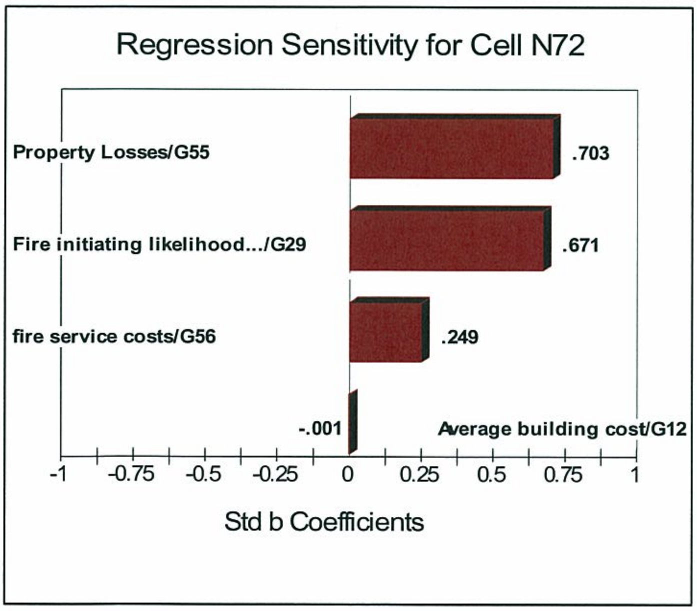
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	314	5%	384
Maximum	1425	10%	412
Mean	624	15%	438
Std Dev	171	20%	462
Variance	29107.23722	25%	487
Skewness	0.561506835	30%	511
Kurtosis	2.989619113	35%	533
Median	608	40%	559
Mode	531	45%	584
Left X	384	50%	608
Left P	5%	55%	633
Right X	927	60%	658
Right P	95%	65%	684
Diff X	543	70%	709
Diff P	90%	75%	738
#Errors	0	80%	770
Filter Min		85%	807
Filter Max		90%	853
#Filtered	0	95%	927

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	with sprinklers / $	0.866	0.899
#2	Floor area / G	-0.325	-0.318
#3	Property Losses	0.149	0.131
#4	Fire initiating like	0.146	0.134
#5	Probability of aut	0.145	0.127
#6	Probability of det	0.099	0.072
#7	Sprinkler system	0.062	0.202
#8	fire service costs	0.053	0.038
#9	Extinguisher mai	0.022	0.133
#10	Extinguisher cos	0.005	-0.109
#11	Assumed height	0.000	-0.004
#12	Average building	0.000	0.002
#13	Probability of det	0.000	-0.003
#14	Probability of ma	0.000	-0.006
#15	Probability of fire	0.000	-0.007
#16	With detection &	0.000	0.005

Simulation Results for
Fire controlled by fire service intervention (80% damage) / of fire / N72





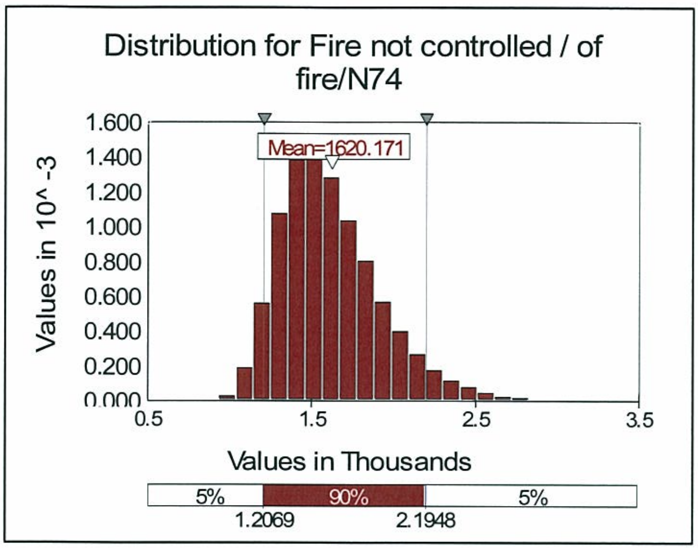


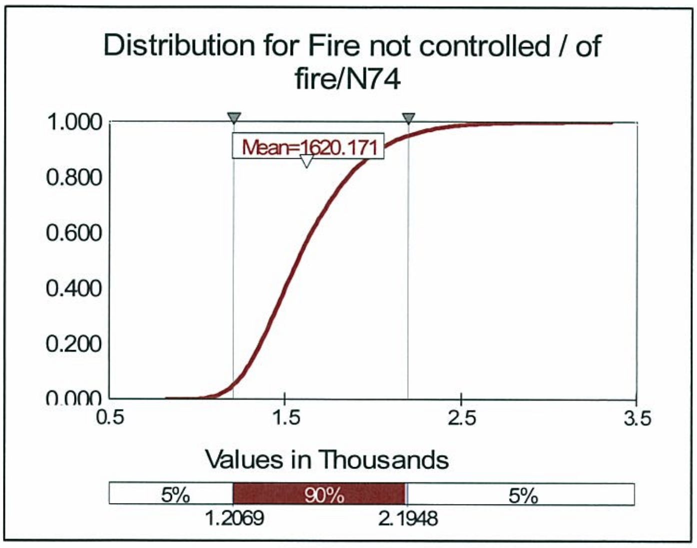
Summary Information	
Workbook Name	Simulation 1 residential.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	17
Number of Outputs	6
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 12:40
Simulation Stop Time	29/09/2008 12:41
Simulation Duration	00:01:23
Random Seed	1005917417

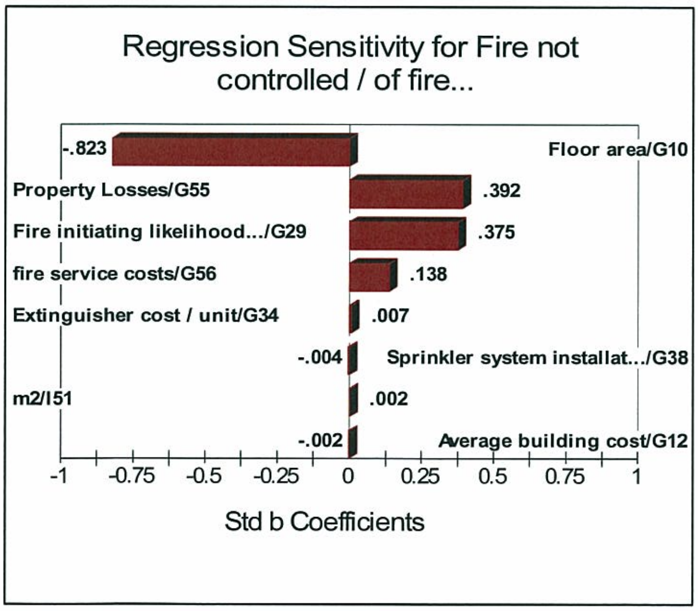
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	466	5%	642
Maximum	1083	10%	669
Mean	775	15%	689
Std Dev	81	20%	705
Variance	6632.937791	25%	719
Skewness	0.063113143	30%	731
Kurtosis	2.874961997	35%	743
Median	774	40%	753
Mode	771	45%	764
Left X	642	50%	774
Left P	5%	55%	784
Right X	910	60%	795
Right P	95%	65%	806
Diff X	269	70%	818
Diff P	90%	75%	830
#Errors	0	80%	844
Filter Min		85%	860
Filter Max		90%	880
#Filtered	0	95%	910

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Property Losses	0.703	0.674
#2	Fire initiating like	0.671	0.654
#3	fire service costs	0.249	0.237
#4	Average building	-0.001	-0.006
#5	Floor area / G	0.000	0.009
#6	Assumed height	0.000	-0.005
#7	Probability of det	0.000	0.004
#8	Probability of det	0.000	-0.006
#9	Probability of ma	0.000	-0.004
#10	Probability of aut	0.000	-0.009
#11	Probability of fire	0.000	0.008
#12	Extinguisher cos	0.000	0.005
#13	Extinguisher mai	0.000	-0.008
#14	Sprinkler system	0.000	-0.005
#15	With detection &	0.000	0.002
#16	with sprinklers / $	0.000	0.006

Simulation Results for
Fire not controlled / of fire / N74







Summary Information	
Workbook Name	Simulation 1 residential.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	17
Number of Outputs	6
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 12:40
Simulation Stop Time	29/09/2008 12:41
Simulation Duration	00:01:23
Random Seed	1005917417

Summary Statistics

Statistic	Value	%tile	Value
Minimum	832	5%	1207
Maximum	3356	10%	1273
Mean	1620	15%	1321
Std Dev	306	20%	1362
Variance	93863.90102	25%	1399
Skewness	0.871087616	30%	1434
Kurtosis	4.024472342	35%	1470
Median	1573	40%	1503
Mode	1534	45%	1537
Left X	1207	50%	1573
Left P	5%	55%	1609
Right X	2195	60%	1648
Right P	95%	65%	1692
Diff X	988	70%	1742
Diff P	90%	75%	1794
#Errors	0	80%	1855
Filter Min		85%	1930
Filter Max		90%	2033
#Filtered	0	95%	2195

Sensitivity

Rank	Name	Regr	Corr
#1	Floor area / G	-0.823	-0.793
#2	Property Losses	0.392	0.390
#3	Fire initiating like	0.375	0.374
#4	fire service costs	0.138	0.133
#5	Extinguisher cos	0.007	-0.302
#6	Sprinkler system	-0.004	0.386
#7	m2 / I51	0.002	0.005
#8	Average building	-0.002	-0.002
#9	Assumed height	0.000	-0.009
#10	Probability of det	0.000	0.003
#11	Probability of det	0.000	-0.002
#12	Probability of ma	0.000	0.000
#13	Probability of aut	0.000	0.005
#14	Probability of fire	0.000	-0.006
#15	Extinguisher mai	0.000	0.315
#16	With detection &	0.000	0.007

Simulation Model 2

Building Type - Care Facility

Risk Input Data

Building Data	Min	most likely	Max		
Floor area	250	394	500	387.67	m^2
Building Cost	1638	2263	2788	2246.33	$\$/m^2$
Assumed height	3.5	5	7	5.08	m
Expected number of employees				8	Persons
Number of compartments				3	Nos.
Aspect Ratio	1	3	6	3.17	
Fire Wall area				112.49	m^2

Cost benefit parameters		
Analysis period	50	Years
Discount rate	8	%
inflation rate	3	%
Real Discount Rate	5	%
life of building	50	Years
life of fire protection system	50	Years
average staff turnover rate	21	%
Capital Recovery Factor (A/P)	0.046	

Fire Protection Systems reliability & effectiveness	Min	most likely	Max	
Probability of detection success (manual)	0.1	0.2	0.3	0.20
Probability of detection success (Automatic)	0.68	0.84	0.9	0.82
Probability of manual suppression success /fire detected	0.2	0.4	0.8	0.43
Probability of automatic sprinkler suppression	0.6	0.8	0.9	0.78
Probability of fire barrier success	0.4	0.65	0.9	0.65

Fire initiating likelihood		
	0.00100916	fires/year/m^2

Fire Protection System costs	Min	most likely	Max		
Fire Alarm fixed cost	2000	3500	7000	3833.33	\$/building
Fire alarm variable cost	9	11	15	11.33	$\$/m^2$
Extinguisher cost / unit	190	220	280	225.00	\$/unit
Number of extinguishers for this model				5	units
Extinguisher maintenance	59	65	80	66.50	\$/year
Extinguisher training cost				34.00	\$/year
Sprinkler system installation cost	35	55	89	57.33	$\$/m^2$
Sprinkler system maintenance cost				700.00	\$/year
Fire service connection cost				1000.00	\$
Fire wall costs	107	130	164	131.83	$\$/m^2$
Total fire protection installation costs				46408	$\$/m^2$
Annualised fire protection install cost over analysis time				2134	\$/year
Total Fire protection cost per year				4167	\$/year
Annualised training costs for the analysis time				199	\$/year

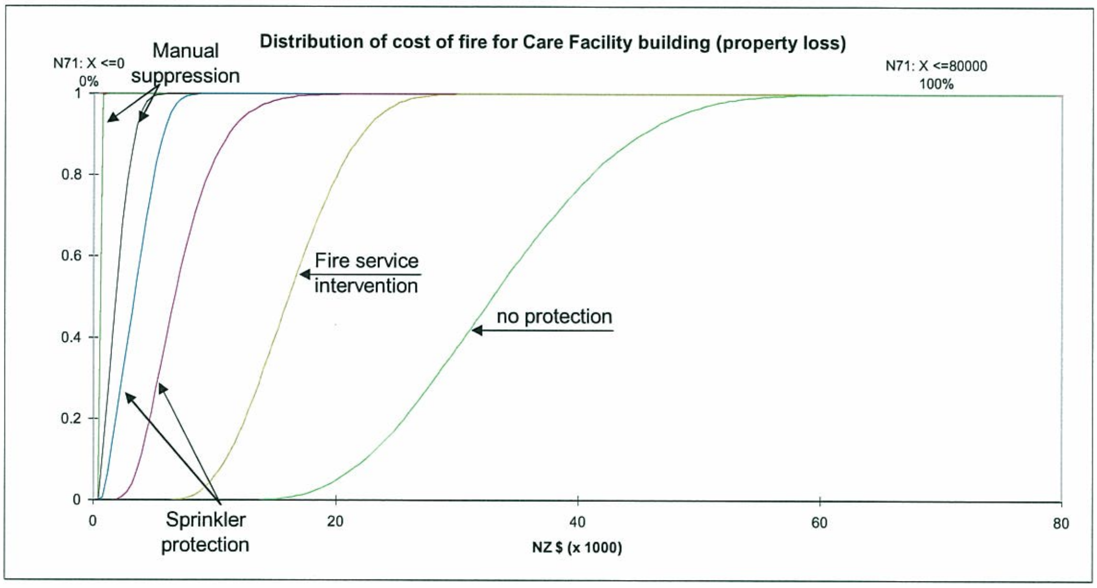
Fire Loss Area				
				m^2
With detection & manual suppression	0	3	1.5	m^2
with sprinklers	3	20	11.5	m^2
with fire wall effectiveness (fire restricted to a single firecell)			129.2	m^2

Fire Loss costs	Mean	SD		
Business interruption costs	268	26.8	268.18	\$/ m^2 of fire loss area
Direct property costs	1207	120.7	1206.82	\$/ m^2 of fire loss area
fire service costs	771	77.1	771.02	\$/ m^2 of fire loss area
indirect economic costs	285	28.5	284.94	\$/ m^2 of fire loss area
reduced consumption costs	70	7.0	70.40	\$/ m^2 of fire loss area
social costs	285	28.5	284.94	\$/ m^2 of fire loss area
Total Fire loss costs			2886.31	\$/ m^2 of fire loss area

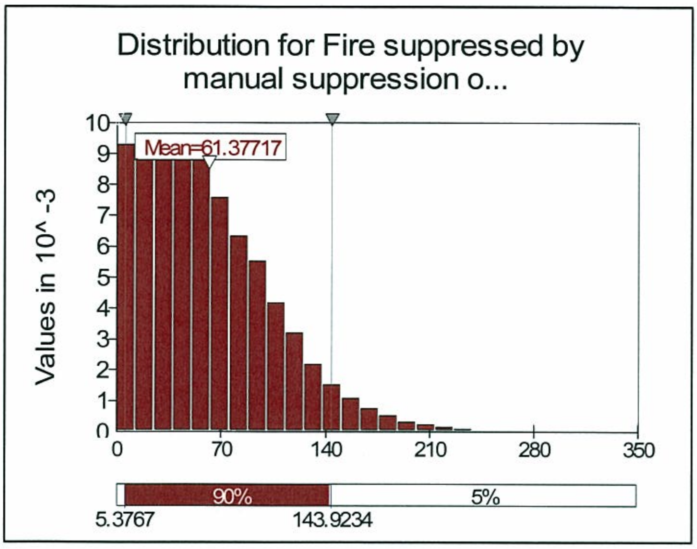
@RISK Correla	Extinguisher c	Extinguisher r	Sprinkler system	2000 in G3	Fire alarm va	Fire wall costs in	Floor area in G1	Assumed height in G12
Extinguisher co	1							
Extinguisher m	0	1						
Sprinkler syste	0	0	1					
2000 in G38	0	0	0	1				
Fire alarm vari	0	0	0	0	1			
Fire wall costs	0	0	0	0	0	1		
Floor area in $	0.4	-0.4	-0.5	0.5	-0.4	0.0	1	

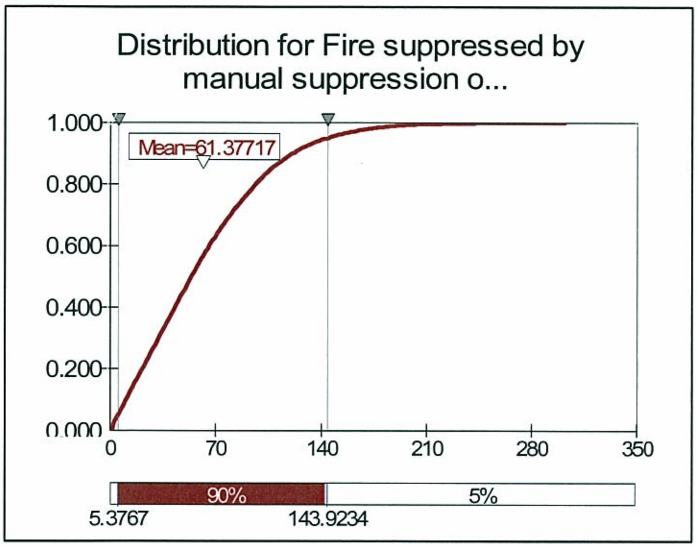
Simulation 2 results table

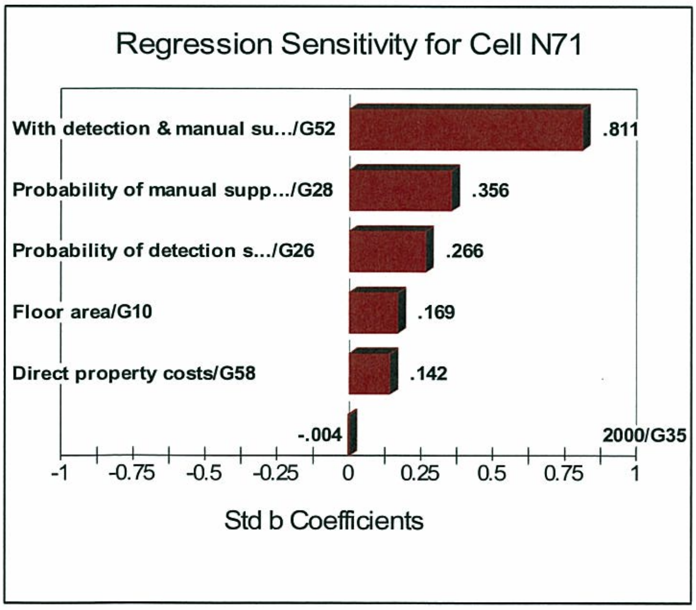
Scenario	Total cost of property loss per fire (NZ$)			other costs (NZ$)	
	Mean	Standard deviation	Upper 95th percentile & rank	Fire Service costs	Indirect Losses
No fire protection (91 - 100% damage)	33428	8645	48393(7)	21048	24800
Fire service intervention (80% damage)	16343	4226	23659(6)	10290	12125
Manual suppression following manual detection	61	44	144(1)	39	46
Manual suppression following automatic detection	253	171	570(2)	161	190
Sprinkler suppression following failure of manual suppression	1985	1025	3865(3)	1268	1494
Sprinkler suppression no manual suppression applied	3502	1641	6337(4)	2237	2636
Fire contained within single compartment due to sprinkler system failure	7178	2904	12636(5)	4520	5325



Simulation Results for
Fire suppressed by manual suppression on manual detection / Property / N71







Summary Information	
Workbook Name	Simulation 2 care facility.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	21
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 15:36
Simulation Stop Time	29/09/2008 15:40
Simulation Duration	00:04:15
Random Seed	196658380

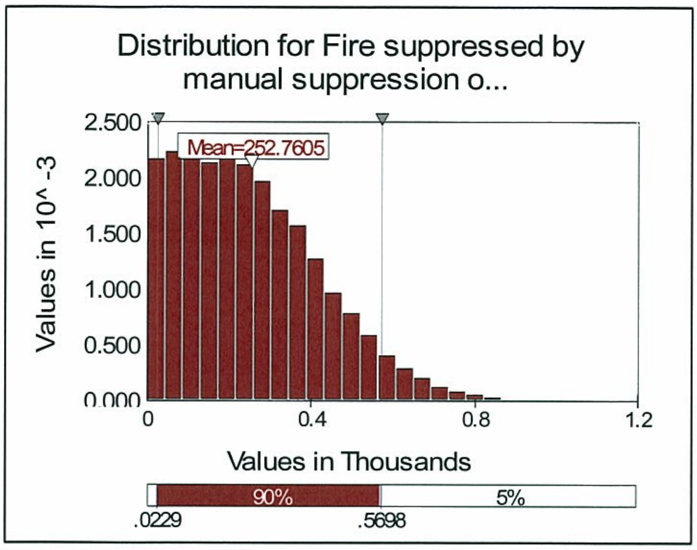
Summary Statistics

Statistic	Value	%tile	Value
Minimum	0.00	5%	5.38
Maximum	301.77	10%	10.76
Mean	61.38	15%	16.16
Std Dev	43.75	20%	21.49
Variance	1914.261923	25%	26.82
Skewness	0.925687023	30%	32.32
Kurtosis	3.837307644	35%	37.63
Median	54.02	40%	43.07
Mode	16.63	45%	48.51
Left X	5.38	50%	54.02
Left P	5%	55%	59.60
Right X	143.92	60%	65.80
Right P	95%	65%	72.34
Diff X	138.55	70%	79.54
Diff P	90%	75%	87.69
#Errors	0	80%	96.45
Filter Min		85%	106.79
Filter Max		90%	121.01
#Filtered	0	95%	143.92

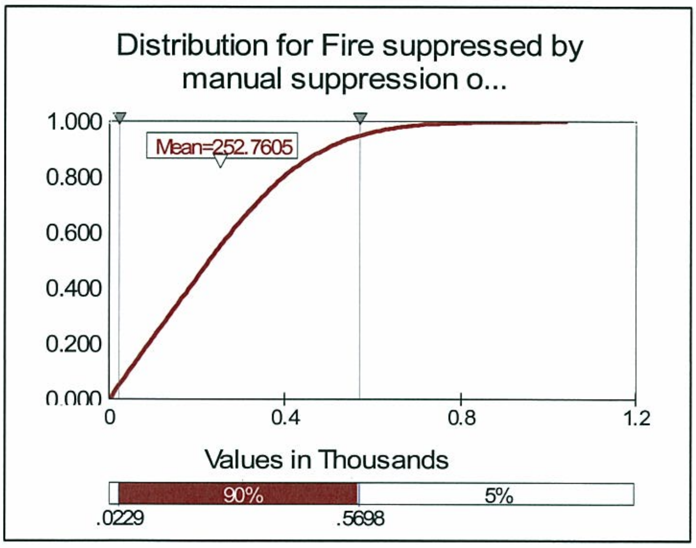
Sensitivity

Rank	Name	Regr	Corr
#1	With detection &	0.811	0.870
#2	Probability of ma	0.356	0.313
#3	Probability of det	0.266	0.227
#4	Floor area / G	0.169	0.148
#5	Direct property c	0.142	0.119
#6	2000 / G35	-0.004	0.000
#7	Assumed height	0.000	-0.007
#8	Probability of det	0.000	-0.007
#9	Probability of aut	0.000	0.000
#10	Probability of fire	0.000	-0.010
#11	Fire alarm variab	0.000	-0.003
#12	Extinguisher cos	0.000	-0.003
#13	Extinguisher mai	0.000	-0.012
#14	Sprinkler system	0.000	0.000
#15	Fire wall costs / $	0.000	-0.014
#16	with sprinklers / $	0.000	0.005

Simulation Results for
Fire suppressed by manual suppression on automatic detection / Property / N7

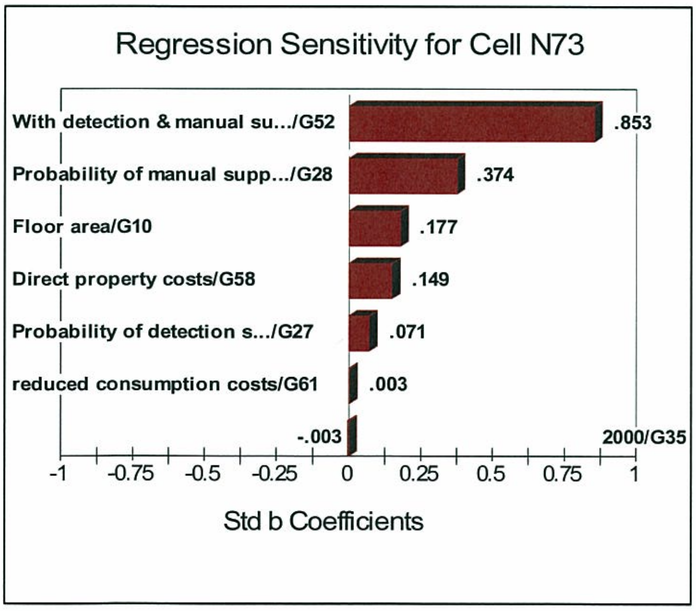


Summary Information	
Workbook Name	Simulation 2 care facility.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	21
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 15:36
Simulation Stop Time	29/09/2008 15:40
Simulation Duration	00:04:15
Random Seed	196658380



Summary Statistics

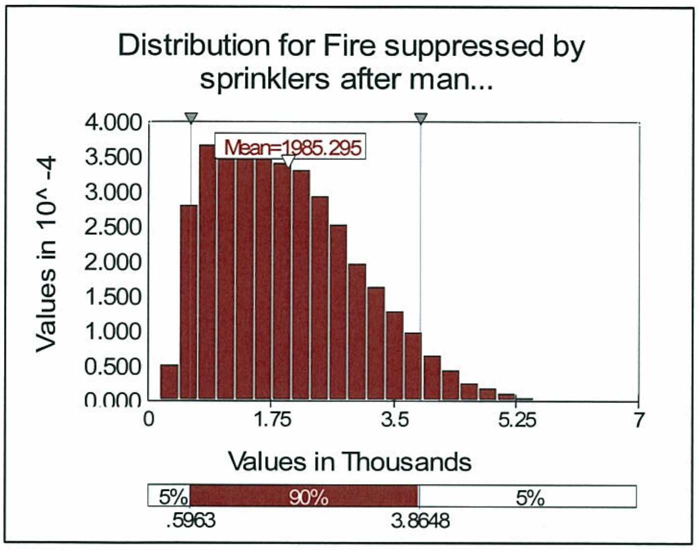
Statistic	Value	%tile	Value
Minimum	0.00	5%	22.94
Maximum	1039.74	10%	46.12
Mean	252.76	15%	68.73
Std Dev	171.38	20%	91.11
Variance	29371.29558	25%	113.99
Skewness	0.709499026	30%	137.29
Kurtosis	3.155118358	35%	159.70
Median	229.18	40%	183.95
Mode	208.80	45%	206.91
Left X	22.94	50%	229.18
Left P	5%	55%	252.27
Right X	569.84	60%	278.21
Right P	95%	65%	303.82
Diff X	546.90	70%	332.47
Diff P	90%	75%	362.64
#Errors	0	80%	396.10
Filter Min		85%	436.92
Filter Max		90%	491.40
#Filtered	0	95%	569.84

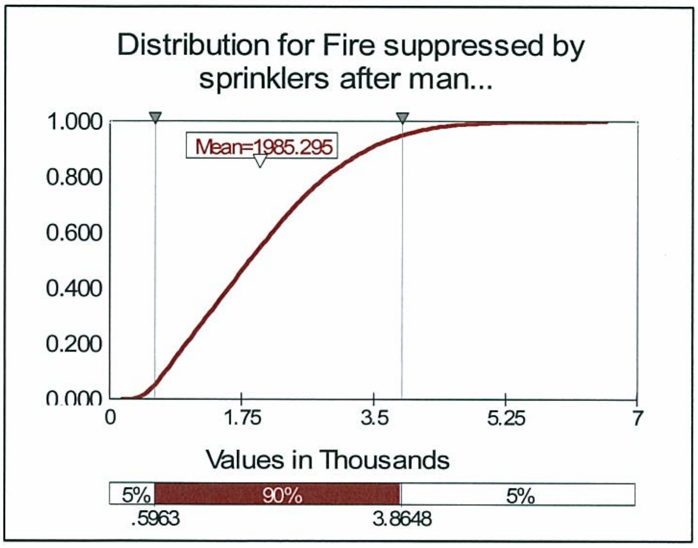


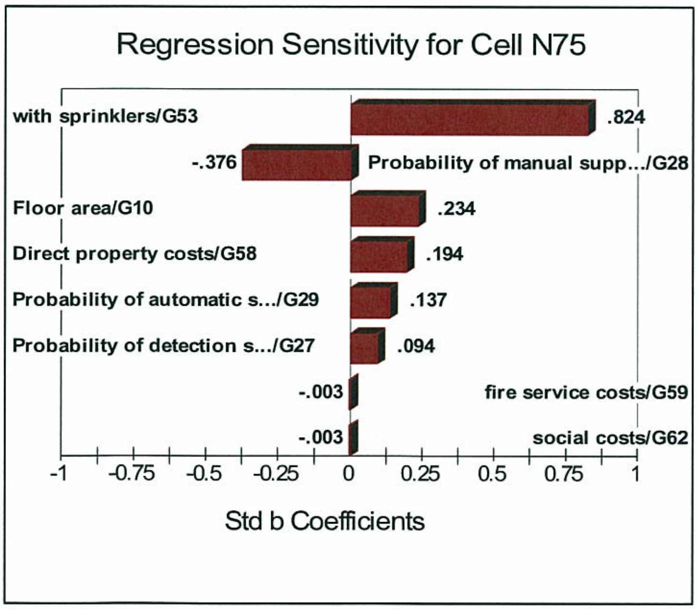
Sensitivity

Rank	Name	Regr	Corr
#1	With detection &	0.853	0.897
#2	Probability of ma	0.374	0.332
#3	Floor area / G	0.177	0.153
#4	Direct property c	0.149	0.123
#5	Probability of det	0.071	0.054
#6	reduced consum	0.003	-0.001
#7	2000 / G35	-0.003	-0.003
#8	Assumed height	0.000	-0.003
#9	Probability of det	0.000	-0.005
#10	Probability of aut	0.000	0.003
#11	Probability of fire	0.000	-0.011
#12	Fire alarm variab	0.000	-0.002
#13	Extinguisher cos	0.000	0.000
#14	Extinguisher mai	0.000	-0.014
#15	Sprinkler system	0.000	0.001
#16	Fire wall costs / $	0.000	-0.012

Simulation Results for
Fire suppressed by sprinklers after manual suppression failed / Property / N75







Summary Information	
Workbook Name	Simulation 2 care facility.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	21
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 15:36
Simulation Stop Time	29/09/2008 15:40
Simulation Duration	00:04:15
Random Seed	196658380

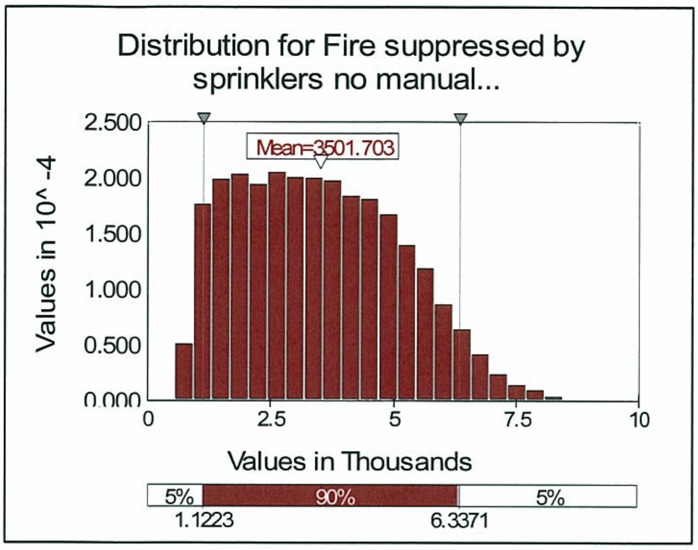
Summary Statistics

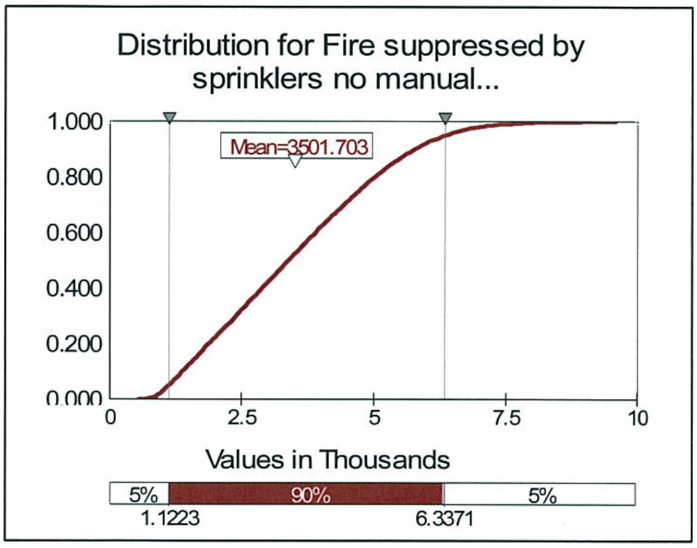
Statistic	Value	%tile	Value
Minimum	176.99	5%	596.29
Maximum	6587.24	10%	746.32
Mean	1985.30	15%	879.06
Std Dev	1025.35	20%	1016.61
Variance	1051349.73	25%	1155.79
Skewness	0.63313038	30%	1296.97
Kurtosis	2.963590971	35%	1435.63
Median	1855.68	40%	1577.98
Mode	786.43	45%	1712.94
Left X	596.29	50%	1855.68
Left P	5%	55%	1999.71
Right X	3864.76	60%	2153.16
Right P	95%	65%	2305.96
Diff X	3268.47	70%	2466.37
Diff P	90%	75%	2650.49
#Errors	0	80%	2857.55
Filter Min		85%	3112.23
Filter Max		90%	3422.20
#Filtered	0	95%	3864.76

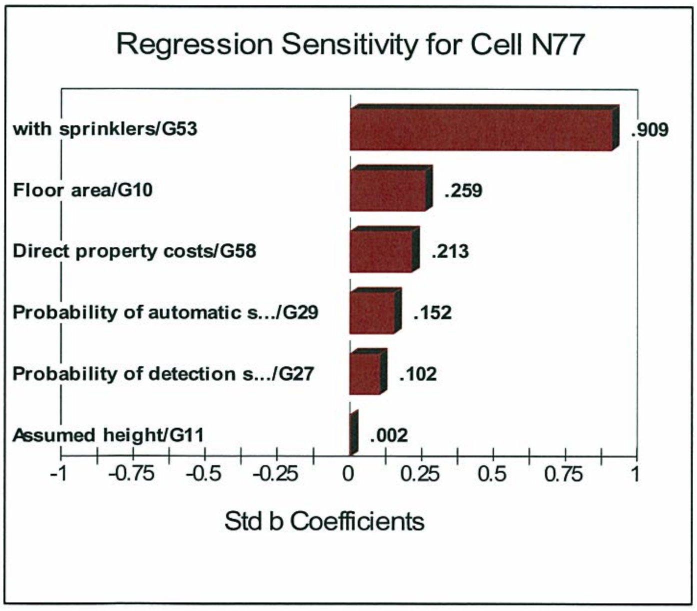
Sensitivity

Rank	Name	Regr	Corr
#1	with sprinklers / $	0.824	0.860
#2	Probability of ma	-0.376	-0.353
#3	Floor area / G	0.234	0.209
#4	Direct property c	0.194	0.168
#5	Probability of aut	0.137	0.117
#6	Probability of det	0.094	0.093
#7	fire service costs	-0.003	-0.003
#8	social costs / $G	-0.003	0.001
#9	Assumed height	0.000	0.006
#10	Probability of det	0.000	0.005
#11	Probability of fire	0.000	0.005
#12	2000 / G35	0.000	-0.004
#13	Fire alarm variab	0.000	-0.003
#14	Extinguisher cos	0.000	0.005
#15	Extinguisher mai	0.000	0.004
#16	Sprinkler system	0.000	-0.002

Simulation Results for
Fire suppressed by sprinklers no manual intervention / Property / N77







Summary Information	
Workbook Name	Simulation 2 care facility.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	21
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 15:36
Simulation Stop Time	29/09/2008 15:40
Simulation Duration	00:04:15
Random Seed	196658380

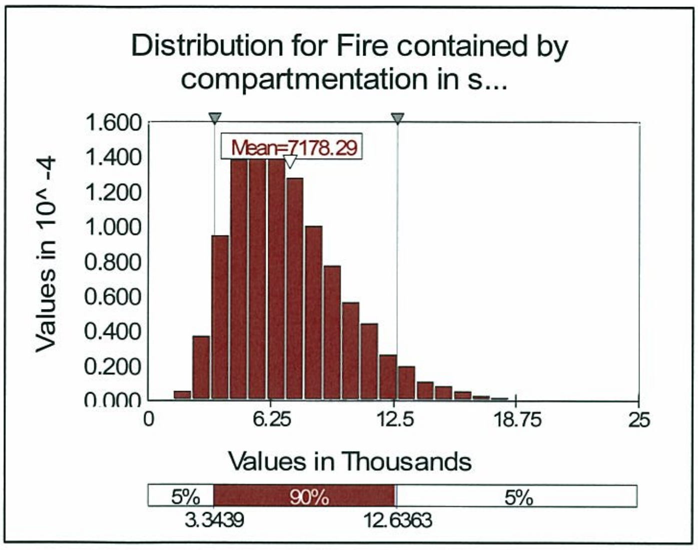
Summary Statistics

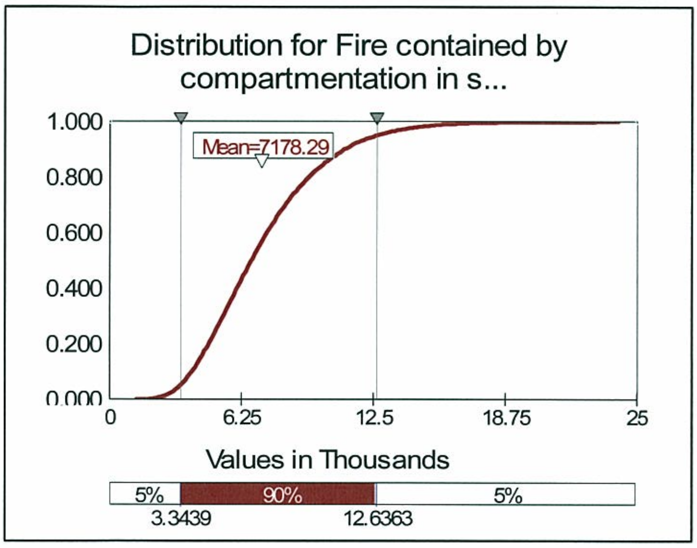
Statistic	Value	%tile	Value
Minimum	558.96	5%	1122.26
Maximum	9589.44	10%	1381.70
Mean	3501.70	15%	1637.17
Std Dev	1641.07	20%	1883.68
Variance	2693097.442	25%	2137.98
Skewness	0.351744371	30%	2396.62
Kurtosis	2.379553606	35%	2638.59
Median	3391.59	40%	2886.86
Mode	1954.90	45%	3138.80
Left X	1122.26	50%	3391.59
Left P	5%	55%	3635.32
Right X	6337.10	60%	3894.97
Right P	95%	65%	4153.96
Diff X	5214.84	70%	4426.38
Diff P	90%	75%	4707.54
#Errors	0	80%	5004.46
Filter Min		85%	5349.51
Filter Max		90%	5758.36
#Filtered	0	95%	6337.10

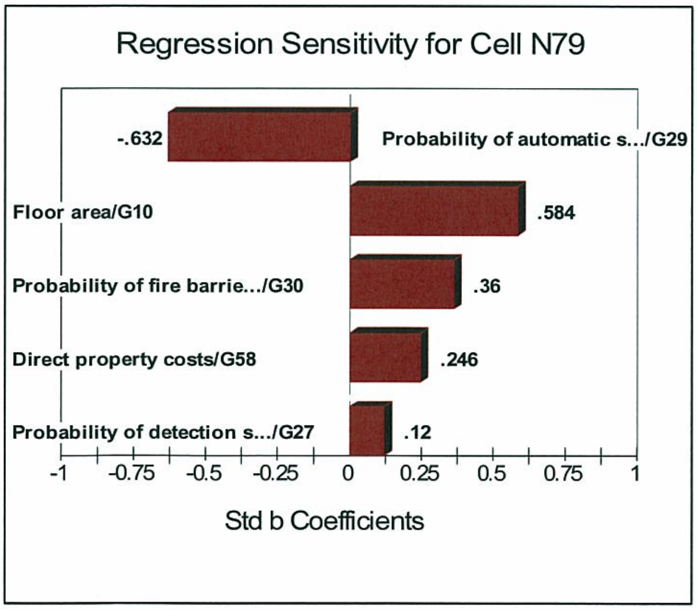
Sensitivity

Rank	Name	Regr	Corr
#1	with sprinklers / $	0.909	0.927
#2	Floor area / G	0.259	0.236
#3	Direct property c	0.213	0.186
#4	Probability of aut	0.152	0.132
#5	Probability of det	0.102	0.099
#6	Assumed height	0.002	0.007
#7	Probability of det	0.000	0.002
#8	Probability of ma	0.000	-0.004
#9	Probability of fire	0.000	0.003
#10	2000 / G35	0.000	-0.003
#11	Fire alarm variab	0.000	-0.004
#12	Extinguisher cos	0.000	0.000
#13	Extinguisher mai	0.000	0.005
#14	Sprinkler system	0.000	-0.004
#15	Fire wall costs / $	0.000	0.005
#16	With detection &	0.000	0.007

Simulation Results for
Fire contained by compartmentation in single fire cell / Property / N79





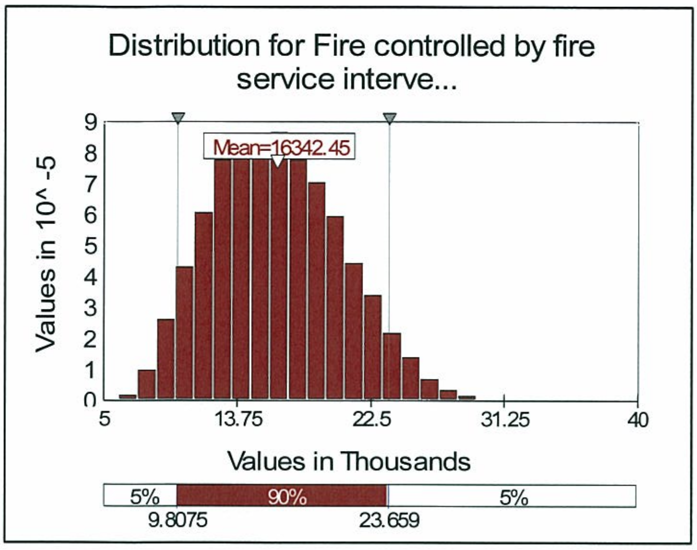


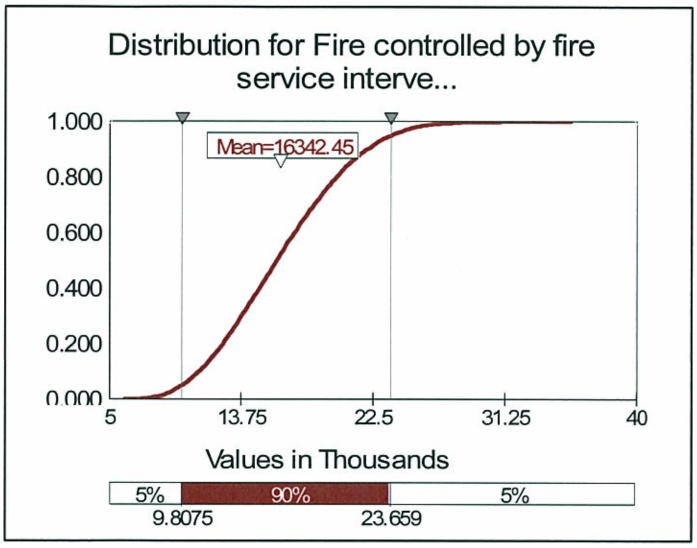
Summary Information	
Workbook Name	Simulation 2 care facility.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	21
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 15:36
Simulation Stop Time	29/09/2008 15:40
Simulation Duration	00:04:15
Random Seed	196658380

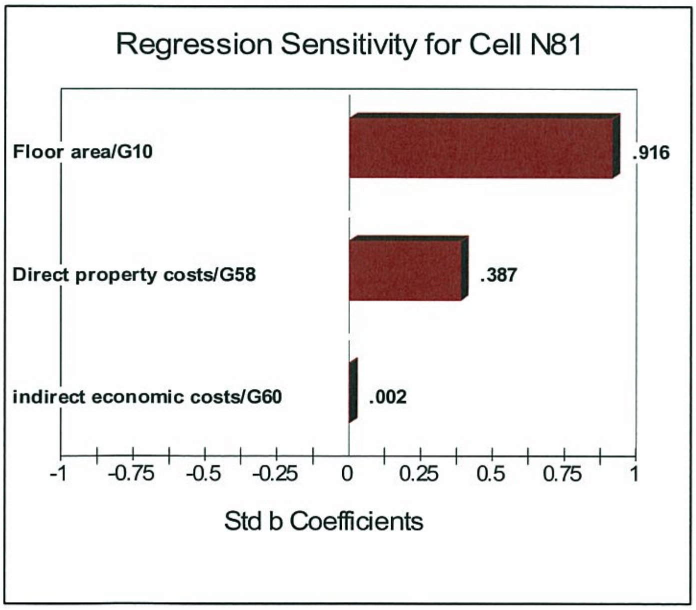
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	1304.13	5%	3343.92
Maximum	24115.26	10%	3890.47
Mean	7178.29	15%	4307.33
Std Dev	2904.02	20%	4686.54
Variance	8433325.744	25%	5030.49
Skewness	0.933341473	30%	5365.20
Kurtosis	4.164508492	35%	5702.52
Median	6703.67	40%	6032.06
Mode	5793.07	45%	6361.94
Left X	3343.92	50%	6703.67
Left P	5%	55%	7077.40
Right X	12636.31	60%	7441.44
Right P	95%	65%	7857.04
Diff X	9292.39	70%	8303.26
Diff P	90%	75%	8818.28
#Errors	0	80%	9412.43
Filter Min		85%	10161.33
Filter Max		90%	11089.92
#Filtered	0	95%	12636.31

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Probability of aut	-0.632	-0.631
#2	Floor area / G	0.584	0.596
#3	Probability of fire	0.360	0.353
#4	Direct property c	0.246	0.242
#5	Probability of det	0.120	0.115
#6	Assumed height	0.000	0.003
#7	Probability of det	0.000	0.009
#8	Probability of ma	0.000	0.002
#9	2000 / G35	0.000	-0.005
#10	Fire alarm variab	0.000	0.008
#11	Extinguisher cos	0.000	-0.007
#12	Extinguisher mai	0.000	-0.006
#13	Sprinkler system	0.000	-0.002
#14	Fire wall costs / $	0.000	-0.012
#15	With detection &	0.000	-0.010
#16	with sprinklers / $	0.000	0.002

Simulation Results for
Fire controlled by fire service intervention / Property / N81







Summary Information	
Workbook Name	Simulation 2 care facility.xl
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	21
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 15:36
Simulation Stop Time	29/09/2008 15:40
Simulation Duration	00:04:15
Random Seed	196658380

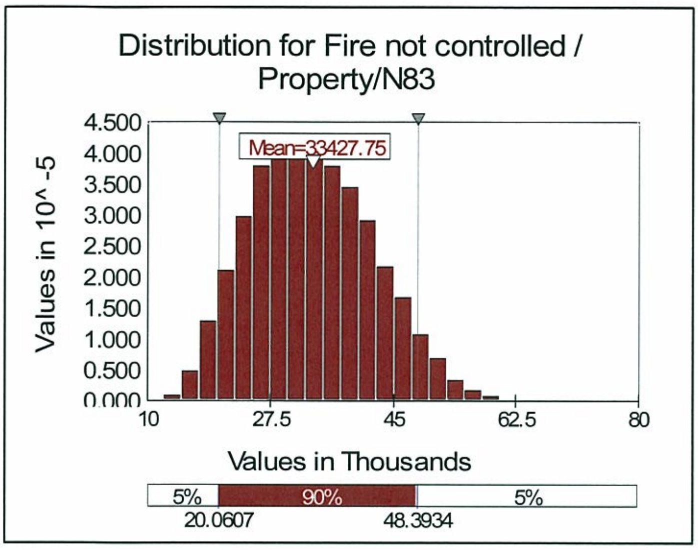
Summary Statistics

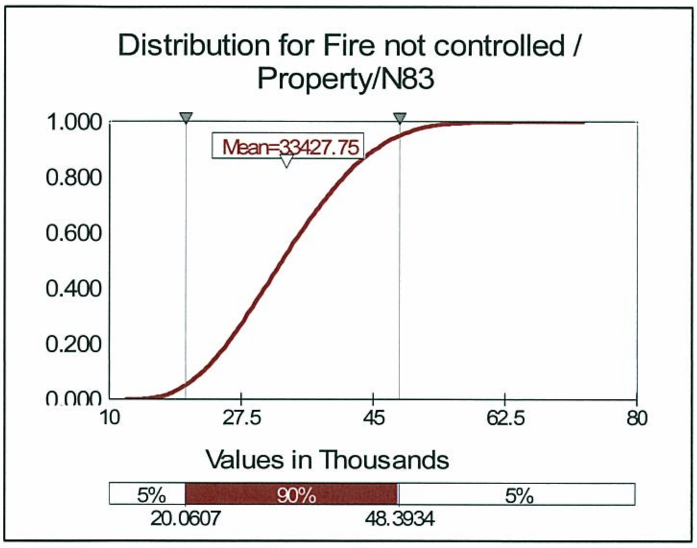
Statistic	Value	%tile	Value
Minimum	6019.53	5%	9807.47
Maximum	35615.64	10%	10958.08
Mean	16342.45	15%	11794.50
Std Dev	4226.36	20%	12542.33
Variance	17862086.09	25%	13170.84
Skewness	0.276962321	30%	13770.62
Kurtosis	2.625031806	35%	14362.11
Median	16105.87	40%	14950.96
Mode	15819.23	45%	15532.46
Left X	9807.47	50%	16105.87
Left P	5%	55%	16673.06
Right X	23659.01	60%	17287.70
Right P	95%	65%	17901.80
Diff X	13851.54	70%	18584.70
Diff P	90%	75%	19282.74
#Errors	0	80%	20055.99
Filter Min		85%	20944.41
Filter Max		90%	22090.79
#Filtered	0	95%	23659.01

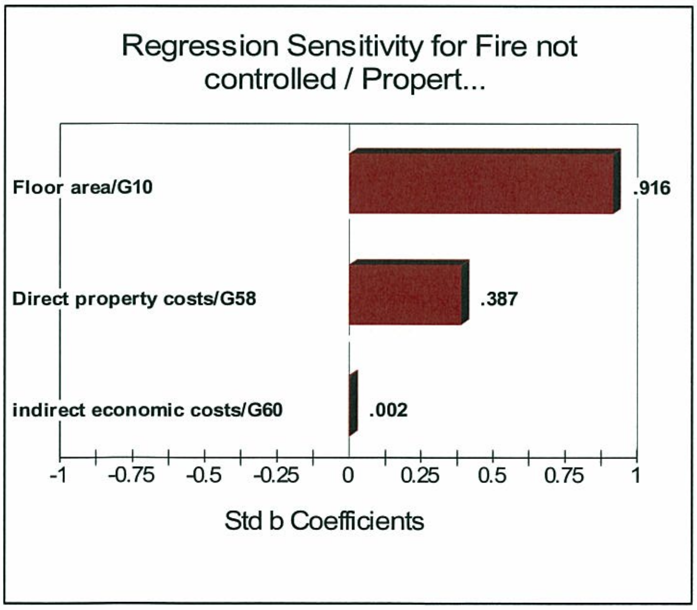
Sensitivity

Rank	Name	Regr	Corr
#1	Floor area / G	0.916	0.922
#2	Direct property c	0.387	0.357
#3	indirect economi	0.002	0.005
#4	Assumed height	0.000	0.006
#5	Probability of det	0.000	0.008
#6	Probability of det	0.000	0.000
#7	Probability of ma	0.000	0.010
#8	Probability of aut	0.000	0.000
#9	Probability of fire	0.000	0.008
#10	2000 / G35	0.000	-0.005
#11	Fire alarm variab	0.000	0.010
#12	Extinguisher cos	0.000	-0.004
#13	Extinguisher mai	0.000	0.002
#14	Sprinkler system	0.000	0.001
#15	Fire wall costs / $	0.000	0.001
#16	With detection &	0.000	-0.002

Simulation Results for
Fire not controlled / Property / N83







Summary Information	
Workbook Name	Simulation 2 care facility.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	21
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 15:36
Simulation Stop Time	29/09/2008 15:40
Simulation Duration	00:04:15
Random Seed	196658380

Summary Statistics

Statistic	Value	%tile	Value
Minimum	12312.68	5%	20060.74
Maximum	72850.17	10%	22414.26
Mean	33427.75	15%	24125.12
Std Dev	8644.82	20%	25654.77
Variance	74732901.41	25%	26940.36
Skewness	0.276962324	30%	28167.18
Kurtosis	2.62503181	35%	29377.04
Median	32943.83	40%	30581.52
Mode	32357.53	45%	31770.94
Left X	20060.74	50%	32943.83
Left P	5%	55%	34103.98
Right X	48393.43	60%	35361.21
Right P	95%	65%	36617.32
Diff X	28332.69	70%	38014.16
Diff P	90%	75%	39441.97
#Errors	0	80%	41023.62
Filter Min		85%	42840.84
Filter Max		90%	45185.70
#Filtered	0	95%	48393.43

Sensitivity

Rank	Name	Regr	Corr
#1	Floor area / G	0.916	0.922
#2	Direct property c	0.387	0.357
#3	indirect economi	0.002	0.005
#4	Assumed height	0.000	0.006
#5	Probability of det	0.000	0.008
#6	Probability of det	0.000	0.000
#7	Probability of ma	0.000	0.010
#8	Probability of aut	0.000	0.000
#9	Probability of fire	0.000	0.008
#10	2000 / G35	0.000	-0.005
#11	Fire alarm variab	0.000	0.010
#12	Extinguisher cos	0.000	-0.004
#13	Extinguisher mai	0.000	0.002
#14	Sprinkler system	0.000	0.001
#15	Fire wall costs / $	0.000	0.001
#16	With detection &	0.000	-0.002

Simulation Model 3

Building Type - Light Commercial

Risk Input Data

Building Data	Min	most likely	Max		
Floor area	350	414	550	426.00	m^2
Assumed height	3.5	5	7	5.08	m
Building Cost	1135	1253	1370	1252.83	$\$/m^2$
Expected number of employees				28	Persons
Number of compartments				2	Nos.
Aspect Ratio	1	3	6	3.17	
Fire Wall area				58.96	m^2

Cost benefit parameters		
Analysis period	50	Years
Discount rate	8	%
inflation rate	3	%
Real Discount Rate	5	%
life of building	50	Years
life of fire protection system	50	Years
average staff turnover rate	21	%
Capital Recovery Factor (A/P)	0.046	

Fire Protection Systems reliability & effectiveness	Min	most likely	Max	
Probability of detection success (manual)	0.1	0.2	0.3	0.20
Probability of detection success (Automatic)	0.68	0.84	0.9	0.82
Probability of manual suppression success /fire detected	0.2	0.4	0.8	0.43
Probability of automatic sprinkler suppression	0.6	0.8	0.9	0.78
Probability of fire barrier success	0.4	0.65	0.9	0.65
Fire initiating likelihood	0.000382	0.001552	0.011491	0.00301352 fires/year/m^2

Fire Protection System costs	Min	most likely	Max		
Fire Alarm fixed cost	2000	3500	7000	3833.33	\$/building
Fire alarm variable cost	9	11	15	11.33	$\$/m^2$
Extinguisher cost / unit	190	220	280	225.00	\$/unit
Number of extinguishers for this model				5	units
Extinguisher maintenance	59	65	80	66.50	\$/year
Extinguisher training cost				34.00	\$/year
Sprinkler system installation cost	35	55	89	57.33	$\$/m^2$
Sprinkler system maintenance cost				700.00	\$/year
Fire service connection cost				1000.00	\$/year
Fire wall costs	107	130	164	131.83	$\$/m^2$
Total fire protection installation costs				41983	\$
Annualised fire protection install cost over analysis time				1931	\$/year
Total Fire protection cost per year				3963	\$/year
Annualised training costs for the analysis time				695	\$/year

Fire Loss Area				
				m^2
With detection & manual suppression	0	3	1.5	m^2
with sprinklers	3	20	11.5	m^2
with fire wall effectiveness			170.4	m^2

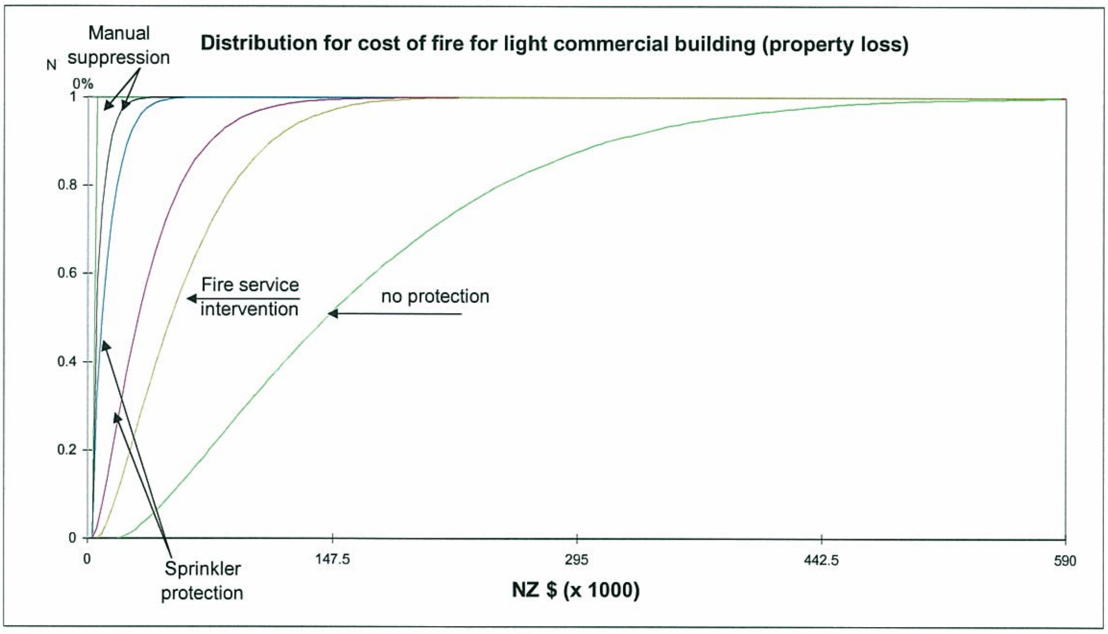
Fire Loss costs	Mean	SD		
Business interruption costs	268	26.8	268.18	$\$/m^2$ of fire loss
Direct property costs	1207	120.7	1206.82	$\$/m^2$ of fire loss
fire service costs	771	77.1	771.02	$\$/m^2$ of fire loss
indirect economic costs	285	28.5	284.94	$\$/m^2$ of fire loss
reduced consumption costs	70	7.0	70.40	$\$/m^2$ of fire loss
social costs	285	28.5	284.94	$\$/m^2$ of fire loss
Total Fire loss costs			2886.31	$\$/m^2$ of fire loss

@RISK Correlation Sheet

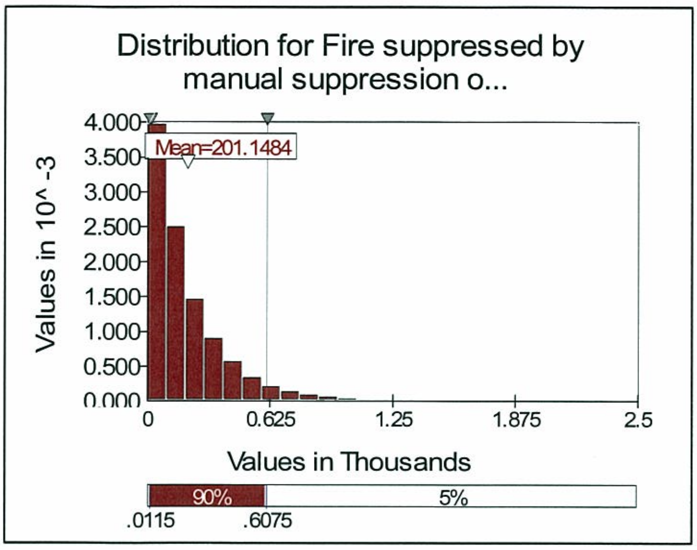
NewMatrix (8x8)	Sheet1!G35 Fire alarm fixed cost	Sheet1!G36 Fire alarm variable cost	Sheet1!G37 Extinguisher cost / unit	Sheet1!G39 Extinguisher maintenance	Sheet1!G41 Sprinkler system installation cost	Sheet1!G44 Fire wall costs	Sheet1!G10 Floor area	Sheet1!G11 Assumed height
Sheet1!G35 Fire alarm fixed cost	1							
Sheet1!G36 Fire alarm variable cost	0	1						
Sheet1!G37 Extinguisher cost / unit	0	0	1					
Sheet1!G39 Extinguisher maintenance	0	0	0	1				
Sheet1!G41 Sprinkler system installation cost	0	0	0	0	1			
Sheet1!G44 Fire wall costs	0	0	0	0	0	1		
Sheet1!G10 Floor area	-0.489543927	0.391635142	0.391635142	-0.391635142	-0.489543927	0	1	
Sheet1!G11 Assumed height	0	0	0	0	0.391635142	0.489543927	0	1

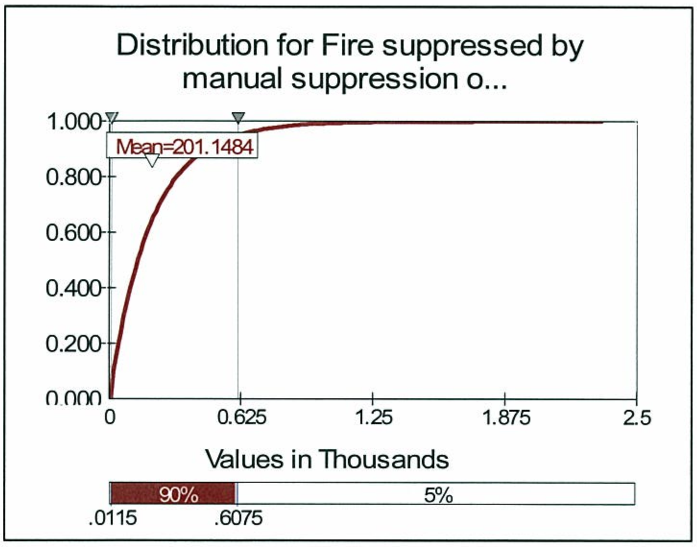
Simulation 3 results table

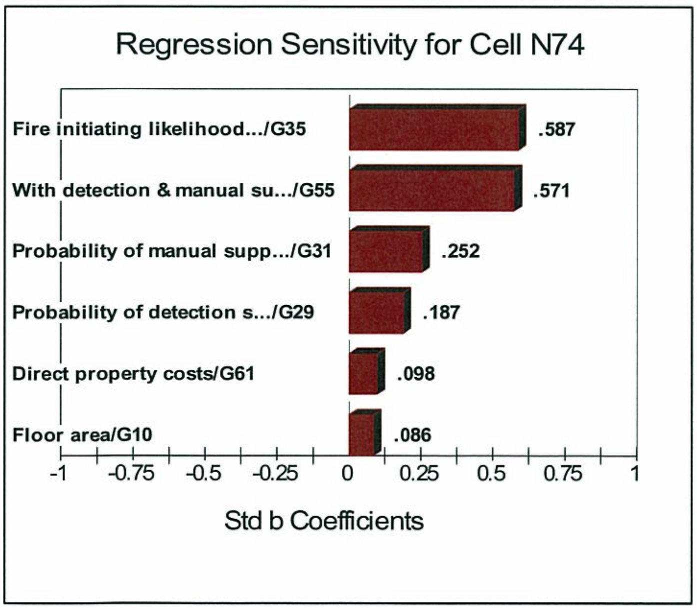
Scenario	Total cost of property loss per year (NZ$)			other costs per year (NZ$)	
	Mean	Standard deviation	Upper 95th percentile & rank	Fire Service costs	Indirect Losses
No fire protection (91 - 100% damage)	166267	105671	372455(7)	21048	24800
Fire service intervention (80% damage)	58526	37196	131104(6)	37106	43720
Manual suppression following manual detection	201	204	608(1)	129	152
Manual suppression following automatic detection	829	813	2484(2)	530	624
Sprinkler suppression following failure of manual suppression	6498	5425	3865(3)	4160	4902
Sprinkler suppression no manual suppression applied	11474	9161	30025(4)	7341	8650
Fire contained within single compartment	37447	27066	90443(5)	23753	27988



Simulation Results for
Fire suppressed by manual suppression on manual detection / Property / N74







Summary Information	
Workbook Name	nulation 3 light commercial
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	24
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 23:45
Simulation Stop Time	30/09/2008 0:01
Simulation Duration	00:16:00
Random Seed	1588344320

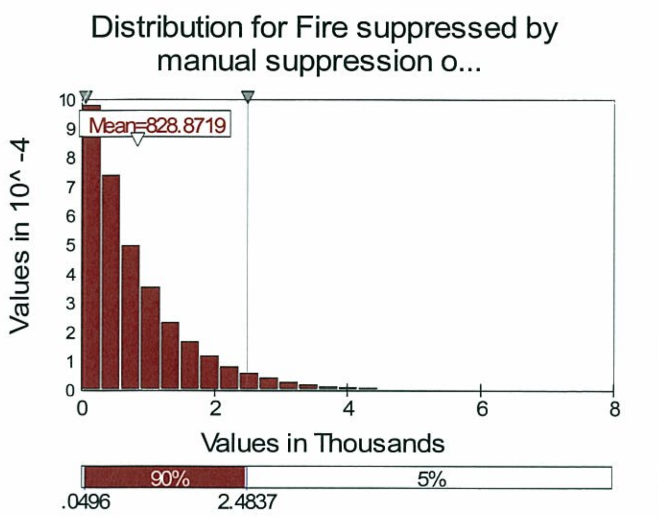
Summary Statistics

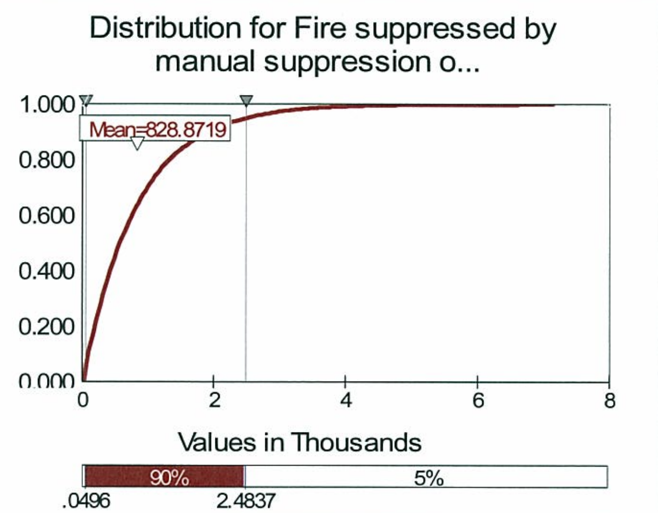
Statistic	Value	%tile	Value
Minimum	0.01	5%	11.54
Maximum	2334.26	10%	23.27
Mean	201.15	15%	34.53
Std Dev	203.71	20%	46.74
Variance	41499.27765	25%	59.45
Skewness	2.103658413	30%	72.25
Kurtosis	9.605540651	35%	86.47
Median	138.23	40%	101.98
Mode	31.06	45%	119.35
Left X	11.54	50%	138.23
Left P	5%	55%	157.76
Right X	607.54	60%	180.14
Right P	95%	65%	207.05
Diff X	596.00	70%	237.64
Diff P	90%	75%	275.15
#Errors	0	80%	320.20
Filter Min		85%	379.36
Filter Max		90%	462.69
#Filtered	0	95%	607.54

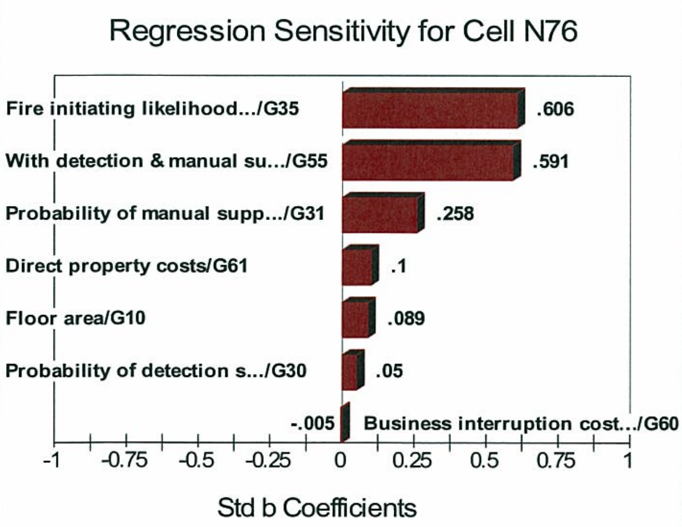
Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.587	0.577
#2	With detection &	0.571	0.694
#3	Probability of ma	0.252	0.221
#4	Probability of det	0.187	0.166
#5	Direct property c	0.098	0.091
#6	Floor area / G	0.086	0.076
#7	Assumed height	0.000	-0.010
#8	Building Cost / $	0.000	-0.011
#9	Probability of det	0.000	0.007
#10	Probability of aut	0.000	0.004
#11	Probability of fire	0.000	-0.006
#12	Fire alarm fixed c	0.000	-0.050
#13	Fire alarm variab	0.000	0.032
#14	Extinguisher cos	0.000	0.029
#15	Extinguisher mai	0.000	-0.029
#16	Sprinkler system	0.000	-0.027

Simulation Results for
Fire suppressed by manual suppression on automatic detection / Property / N7(







Summary Information	
Workbook Name	nulation 3 light commercial
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	24
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 23:45
Simulation Stop Time	30/09/2008 0:01
Simulation Duration	00:16:00
Random Seed	1588344320

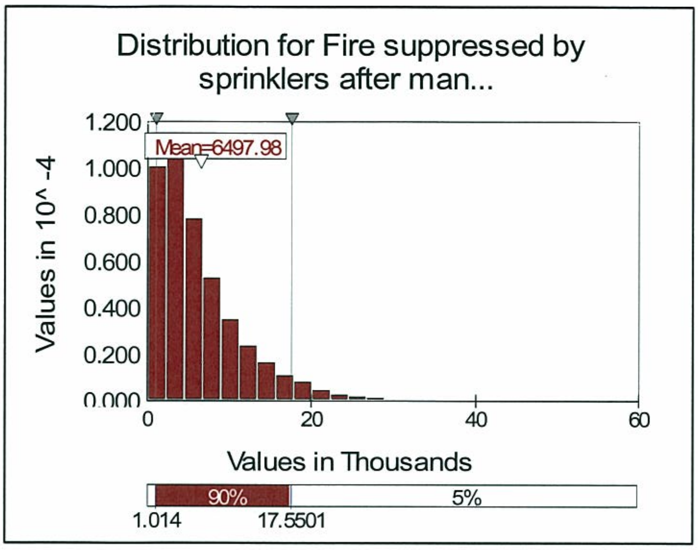
Summary Statistics

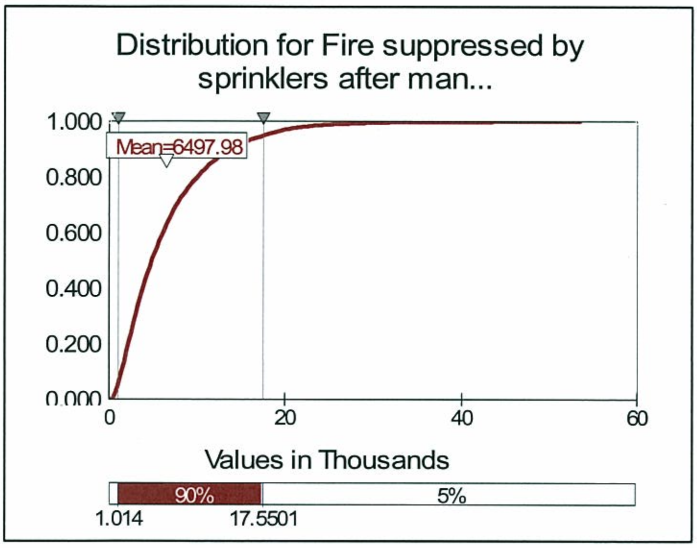
Statistic	Value	%tile	Value
Minimum	0.05	5%	49.55
Maximum	7141.11	10%	98.29
Mean	828.87	15%	148.22
Std Dev	812.56	20%	199.00
Variance	660254.1269	25%	250.90
Skewness	1.903453712	30%	305.76
Kurtosis	7.990734133	35%	365.61
Median	573.91	40%	429.47
Mode	93.75	45%	500.70
Left X	49.55	50%	573.91
Left P	5%	55%	664.77
Right X	2483.68	60%	760.12
Right P	95%	65%	868.62
Diff X	2434.13	70%	993.61
Diff P	90%	75%	1138.82
#Errors	0	80%	1322.90
Filter Min		85%	1571.20
Filter Max		90%	1906.67
#Filtered	0	95%	2483.68

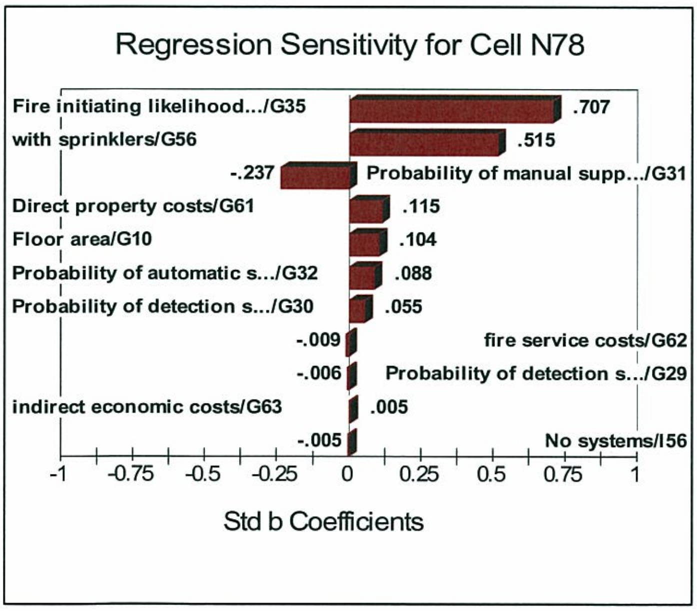
Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.606	0.588
#2	With detection &	0.591	0.703
#3	Probability of ma	0.258	0.230
#4	Direct property c	0.100	0.089
#5	Floor area / G	0.089	0.077
#6	Probability of det	0.050	0.047
#7	Business interru	-0.005	-0.009
#8	Assumed height	0.000	-0.009
#9	Building Cost / $	0.000	-0.010
#10	Probability of det	0.000	-0.004
#11	Probability of aut	0.000	0.003
#12	Probability of fire	0.000	-0.005
#13	Fire alarm fixed c	0.000	-0.048
#14	Fire alarm variab	0.000	0.033
#15	Extinguisher cos	0.000	0.026
#16	Extinguisher mai	0.000	-0.030

Simulation Results for
Fire suppressed by sprinklers after manual suppression failed / Property / N78





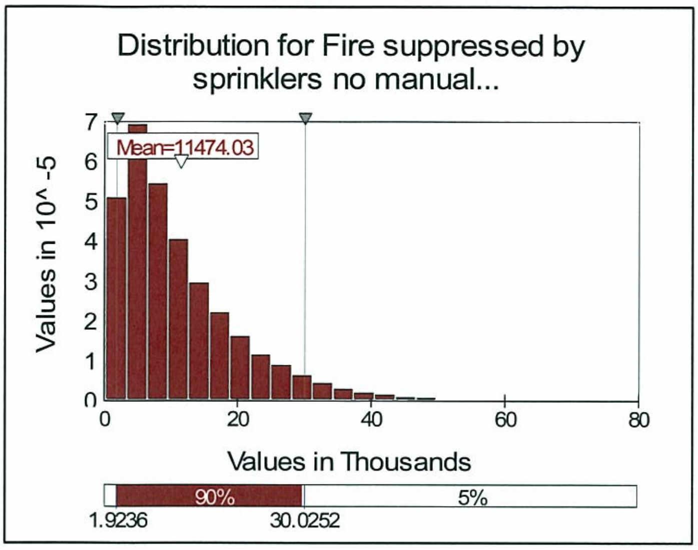


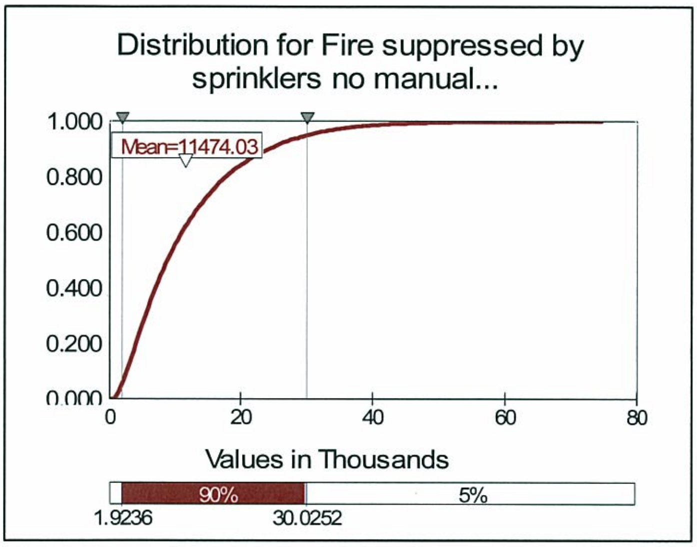
Summary Information	
Workbook Name	nulation 3 light commercial
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	24
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 23:45
Simulation Stop Time	30/09/2008 0:01
Simulation Duration	00:16:00
Random Seed	1588344320

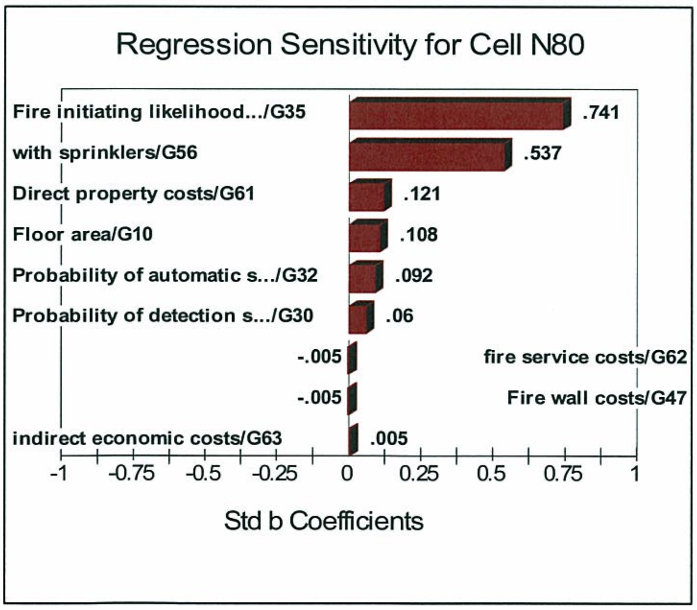
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	152.06	5%	1014.00
Maximum	53498.41	10%	1446.79
Mean	6497.98	15%	1835.67
Std Dev	5425.24	20%	2195.35
Variance	29433258.89	25%	2593.45
Skewness	1.742773338	30%	2990.29
Kurtosis	7.195089674	35%	3417.92
Median	4899.40	40%	3865.91
Mode	1939.17	45%	4355.80
Left X	1014.00	50%	4899.40
Left P	5%	55%	5511.51
Right X	17550.10	60%	6164.01
Right P	95%	65%	6877.53
Diff X	16536.10	70%	7681.35
Diff P	90%	75%	8735.97
#Errors	0	80%	10039.54
Filter Min		85%	11592.20
Filter Max		90%	13827.17
#Filtered	0	95%	17550.10

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Fire initiating like	0.707	0.742
#2	with sprinklers / $	0.515	0.552
#3	Probability of ma	-0.237	-0.226
#4	Direct property c	0.115	0.108
#5	Floor area / G	0.104	0.109
#6	Probability of aut	0.088	0.083
#7	Probability of det	0.055	0.054
#8	fire service costs	-0.009	-0.002
#9	Probability of det	-0.006	0.008
#10	indirect economi	0.005	0.004
#11	No systems / I	-0.005	0.002
#12	Assumed height	0.000	-0.012
#13	Building Cost / $	0.000	0.004
#14	Probability of fire	0.000	0.000
#15	Fire alarm fixed c	0.000	-0.063
#16	Fire alarm variab	0.000	0.039

Simulation Results for
Fire suppressed by sprinklers no manual intervention / Property / N80







Summary Information	
Workbook Name	ıulation 3 light commercial
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	24
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 23:45
Simulation Stop Time	30/09/2008 0:01
Simulation Duration	00:16:00
Random Seed	1588344320

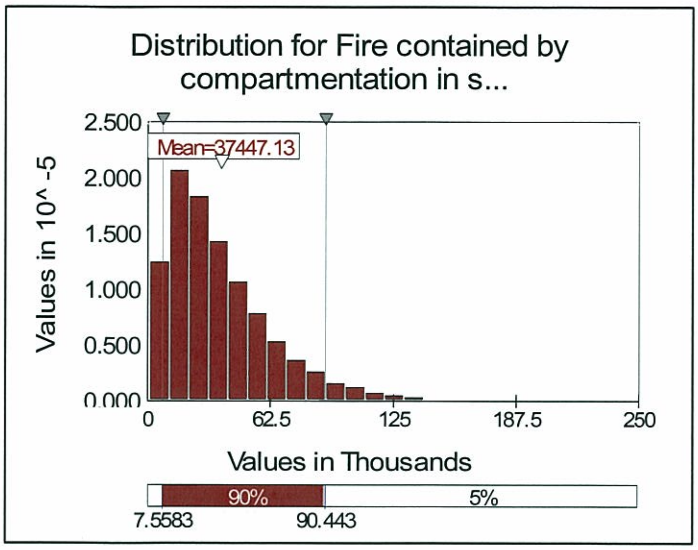
Summary Statistics

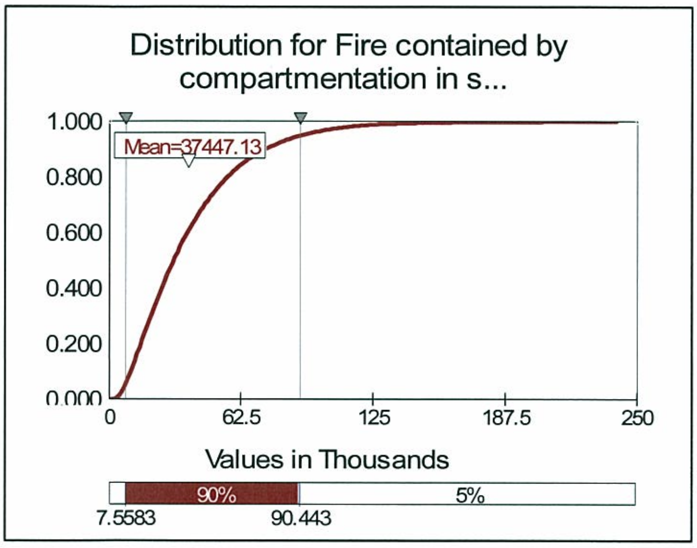
Statistic	Value	%tile	Value
Minimum	369.61	5%	1923.59
Maximum	74637.94	10%	2678.84
Mean	11474.03	15%	3371.63
Std Dev	9160.63	20%	4070.56
Variance	83917086.46	25%	4735.31
Skewness	1.564750896	30%	5470.65
Kurtosis	6.08579602	35%	6223.28
Median	8817.28	40%	7015.02
Mode	3023.03	45%	7889.95
Left X	1923.59	50%	8817.28
Left P	5%	55%	9871.20
Right X	30025.20	60%	11031.05
Right P	95%	65%	12340.11
Diff X	28101.61	70%	13840.85
Diff P	90%	75%	15622.06
#Errors	0	80%	17657.92
Filter Min		85%	20448.81
Filter Max		90%	24104.05
#Filtered	0	95%	30025.20

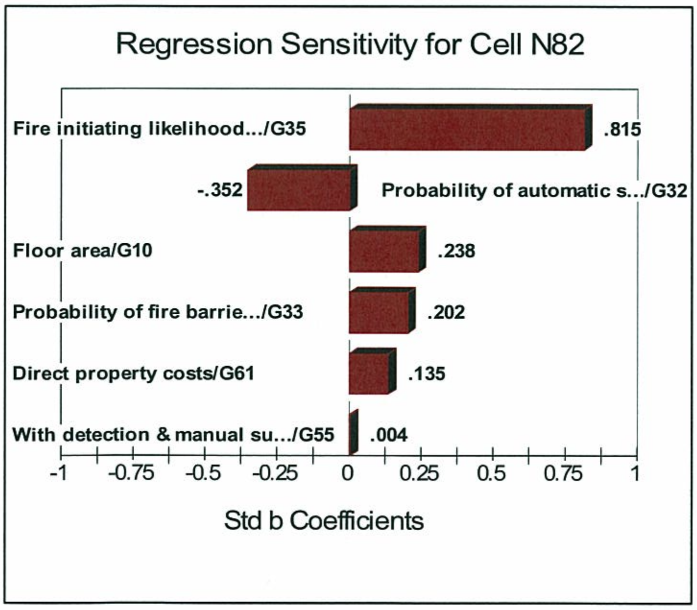
Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.741	0.765
#2	with sprinklers / $	0.537	0.570
#3	Direct property c	0.121	0.112
#4	Floor area / G	0.108	0.111
#5	Probability of aut	0.092	0.084
#6	Probability of det	0.060	0.055
#7	fire service costs	-0.005	-0.002
#8	Fire wall costs / $	-0.005	-0.005
#9	indirect economi	0.005	0.005
#10	Assumed height	0.000	-0.010
#11	Building Cost / $	0.000	0.003
#12	Probability of det	0.000	0.004
#13	Probability of ma	0.000	0.001
#14	Probability of fire	0.000	-0.001
#15	Fire alarm fixed c	0.000	-0.063
#16	Fire alarm variab	0.000	0.042

Simulation Results for
Fire contained by compartmentation in single fire cell / Property / N82







Summary Information	
Workbook Name	nulation 3 light commercial
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	24
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 23:45
Simulation Stop Time	30/09/2008 0:01
Simulation Duration	00:16:00
Random Seed	1588344320

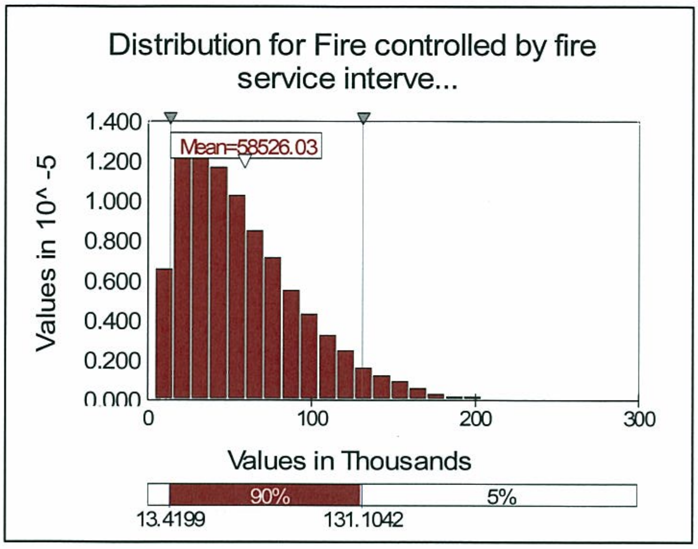
Summary Statistics

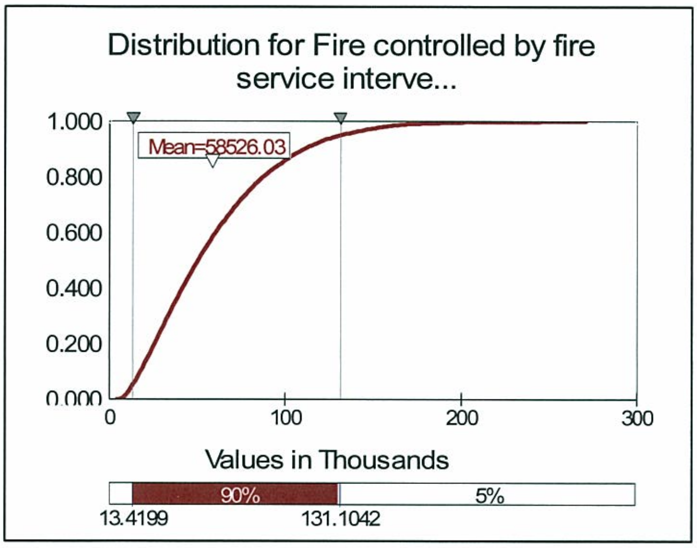
Statistic	Value	%tile	Value
Minimum	1431.63	5%	7558.28
Maximum	240138.86	10%	10251.61
Mean	37447.13	15%	12767.78
Std Dev	27065.82	20%	15159.51
Variance	732558784.4	25%	17457.52
Skewness	1.514352874	30%	19929.40
Kurtosis	6.211756017	35%	22397.32
Median	30655.55	40%	24973.85
Mode	15374.29	45%	27689.00
Left X	7558.28	50%	30655.55
Left P	5%	55%	33680.33
Right X	90442.95	60%	37218.77
Right P	95%	65%	41061.34
Diff X	82884.67	70%	45252.65
Diff P	90%	75%	50259.93
#Errors	0	80%	56025.81
Filter Min		85%	63189.98
Filter Max		90%	73949.15
#Filtered	0	95%	90442.95

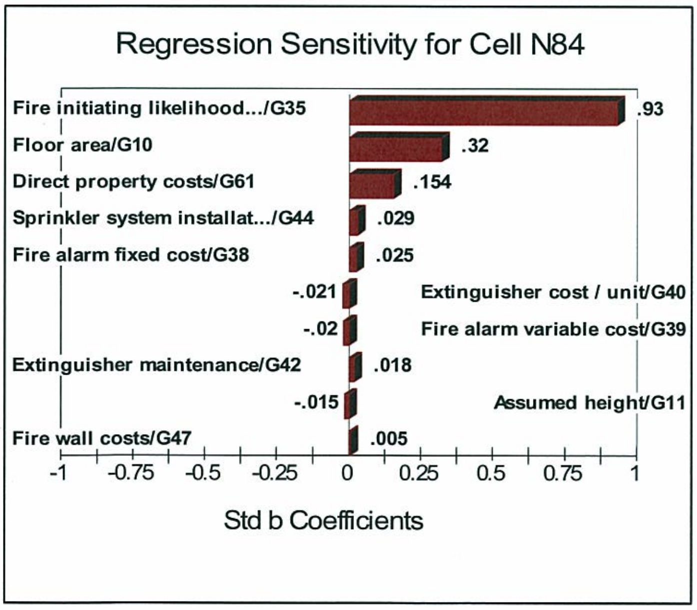
Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.815	0.870
#2	Probability of aut	-0.352	-0.336
#3	Floor area / G	0.238	0.225
#4	Probability of fire	0.202	0.187
#5	Direct property c	0.135	0.126
#6	With detection &	0.004	-0.006
#7	Assumed height	0.000	-0.018
#8	Building Cost / $	0.000	0.001
#9	Probability of det	0.000	-0.007
#10	Probability of det	0.000	-0.001
#11	Probability of ma	0.000	-0.002
#12	Fire alarm fixed c	0.000	-0.121
#13	Fire alarm variab	0.000	0.087
#14	Extinguisher cos	0.000	0.079
#15	Extinguisher mai	0.000	-0.088
#16	Sprinkler system	0.000	-0.108

Simulation Results for
Fire controlled by fire service intervention (80% damage) / Property / N84







Summary Information	
Workbook Name	nulation 3 light commercial
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	24
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 23:45
Simulation Stop Time	30/09/2008 0:01
Simulation Duration	00:16:00
Random Seed	1588344320

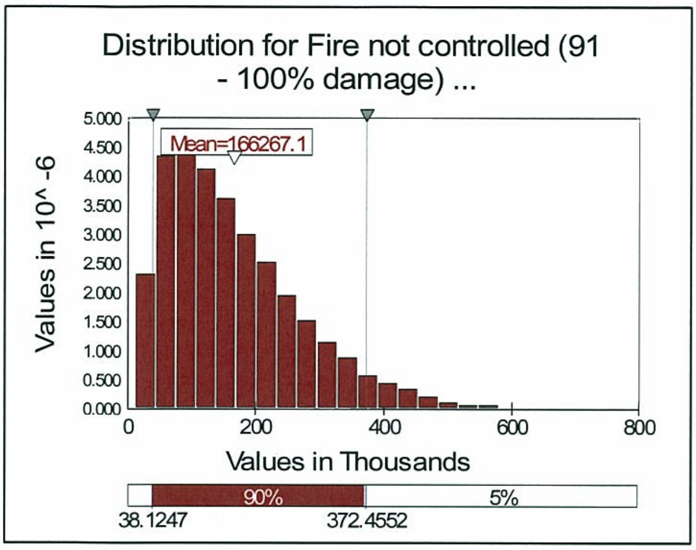
Summary Statistics

Statistic	Value	%tile	Value
Minimum	4455.38	5%	13419.88
Maximum	270867.13	10%	17886.36
Mean	58526.03	15%	22036.69
Std Dev	37196.36	20%	25897.85
Variance	1383569372	25%	29753.63
Skewness	1.069381339	30%	33625.40
Kurtosis	4.150742854	35%	37611.06
Median	50562.16	40%	41672.99
Mode	30829.68	45%	45980.37
Left X	13419.88	50%	50562.16
Left P	5%	55%	55371.32
Right X	131104.22	60%	60474.65
Right P	95%	65%	66345.20
Diff X	117684.34	70%	72484.12
Diff P	90%	75%	79166.74
#Errors	0	80%	87172.13
Filter Min		85%	97604.47
Filter Max		90%	110237.31
#Filtered	0	95%	131104.22

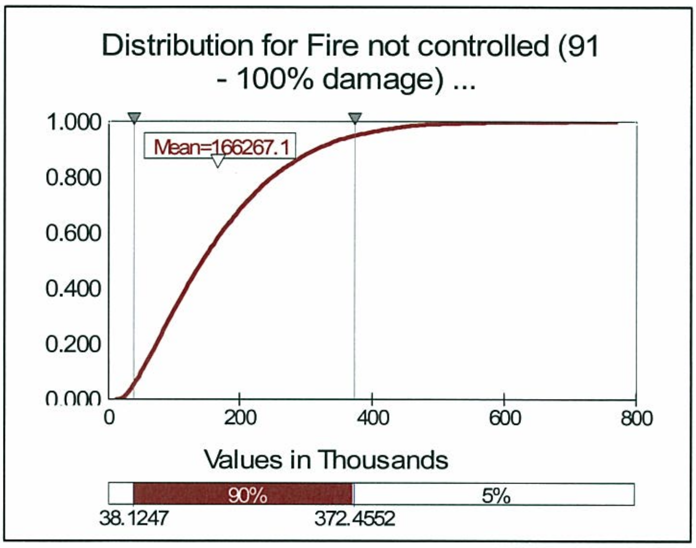
Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.930	0.954
#2	Floor area / G	0.320	0.249
#3	Direct property c	0.154	0.135
#4	Sprinkler system	0.029	-0.117
#5	Fire alarm fixed c	0.025	-0.135
#6	Extinguisher cos	-0.021	0.089
#7	Fire alarm variab	-0.020	0.097
#8	Extinguisher mai	0.018	-0.095
#9	Assumed height	-0.015	-0.014
#10	Fire wall costs / $	0.005	-0.008
#11	Building Cost / $	0.000	-0.001
#12	Probability of det	0.000	-0.004
#13	Probability of det	0.000	-0.002
#14	Probability of ma	0.000	-0.003
#15	Probability of aut	0.000	0.000
#16	Probability of fire	0.000	-0.003

Simulation Results for
Fire not controlled (91 - 100% damage) / Property / N86

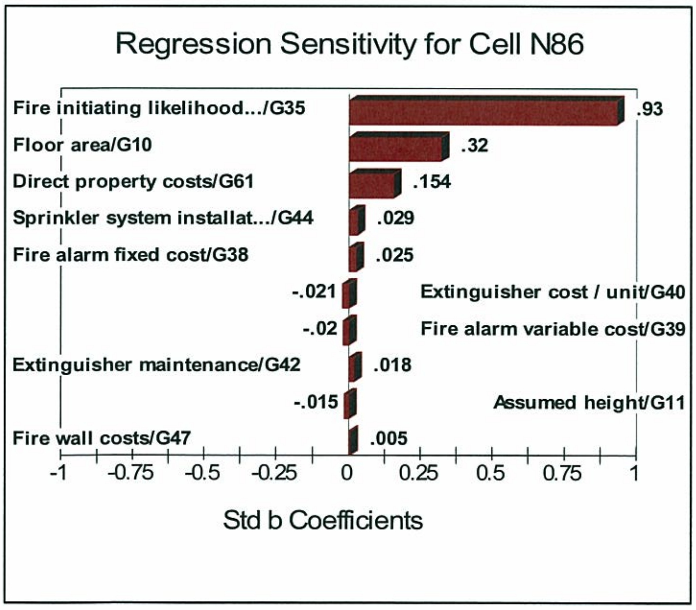


Summary Information	
Workbook Name	ιulation 3 light commercial
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	24
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	29/09/2008 23:45
Simulation Stop Time	30/09/2008 0:01
Simulation Duration	00:16:00
Random Seed	1588344320



Summary Statistics

Statistic	Value	%tile	Value
Minimum	12657.32	5%	38124.66
Maximum	769508.88	10%	50813.53
Mean	166267.12	15%	62604.23
Std Dev	105671.48	20%	73573.43
Variance	11166462532	25%	84527.35
Skewness	1.069381337	30%	95526.71
Kurtosis	4.150742829	35%	106849.59
Median	143642.48	40%	118389.19
Mode	87584.33	45%	130626.05
Left X	38124.66	50%	143642.48
Left P	5%	55%	157304.88
Right X	372455.19	60%	171802.97
Right P	95%	65%	188480.67
Diff X	334330.52	70%	205920.80
Diff P	90%	75%	224905.52
#Errors	0	80%	247648.11
Filter Min		85%	277285.41
Filter Max		90%	313174.19
#Filtered	0	95%	372455.19



Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.930	0.954
#2	Floor area / G	0.320	0.249
#3	Direct property c	0.154	0.135
#4	Sprinkler system	0.029	-0.117
#5	Fire alarm fixed c	0.025	-0.135
#6	Extinguisher cos	-0.021	0.089
#7	Fire alarm variab	-0.020	0.097
#8	Extinguisher mai	0.018	-0.095
#9	Assumed height	-0.015	-0.014
#10	Fire wall costs / $	0.005	-0.008
#11	Building Cost / $	0.000	-0.001
#12	Probability of det	0.000	-0.004
#13	Probability of det	0.000	-0.002
#14	Probability of ma	0.000	-0.003
#15	Probability of aut	0.000	0.000
#16	Probability of fire	0.000	-0.003

Simulation Model 4

Building Type - Bulk Retail

Risk Input Data

Building Data	Min	most likely	Max		
Floor area	650	896	1000	872.33	m^2
Assumed height	3.5	5	7	5.08	m
Building Cost	1310	1405	1500	1405.00	$/$m^2$
Expected number of employees				28	Persons
Number of compartments				2	Nos.
Aspect Ratio	1	3	6	3.17	
Fire Wall area				84.37	m^2

Cost benefit parameters		
Analysis period	50	Years
Discount rate	8	%
inflation rate	3	%
Real Discount Rate	5	%
life of building	50	Years
life of fire protection system	50	Years
average staff turnover rate	21	%
Capital Recovery Factor (A/P)	0.046	

Fire Protection Systems reliability & effectiveness	Min	most likely	Max	
Probability of detection success (manual)	0.1	0.2	0.3	0.20
Probability of detection success (Automatic)	0.68	0.84	0.9	0.82
Probability of manual suppression success /fire detected	0.2	0.4	0.8	0.43
Probability of automatic sprinkler suppression	0.6	0.8	0.9	0.78
Probability of fire barrier success	0.4	0.65	0.9	0.65

Fire initiating likelihood	0.000382	0.001552	0.011491	0.0030135	fires/year/m^2

Fire Protection System costs	Min	most likely	Max		
Fire Alarm fixed cost	2000	3500	7000	3833.33	$/building
Fire alarm variable cost	9	11	15	11.33	$/$m^2$
Extinguisher cost / unit	190	220	280	225.00	$/unit
Number of extinguishers for this model				5	units
Extinguisher maintenance	59	65	80	66.50	$/year
Extinguisher training cost				34.00	$/year
Sprinkler system installation cost	35	55	89	57.33	$/$m^2$
Sprinkler system maintenance cost				700.00	$/year
Fire service connection cost				1000.00	$/year
Fire wall costs	107	130	164	131.83	$/$m^2$
Total fire protection installation costs				75981	$
Annualised fire protection install cost over analysis time				3494	$/year
Total Fire protection cost per year				5527	$/year
Annualised training costs for the analysis time				695	$/year

Fire Loss Area				
				m^2
With detection & manual suppression	0	3	1.5	m^2
with sprinklers	3	20	11.5	m^2
with fire wall effectiveness			348.93	m^2

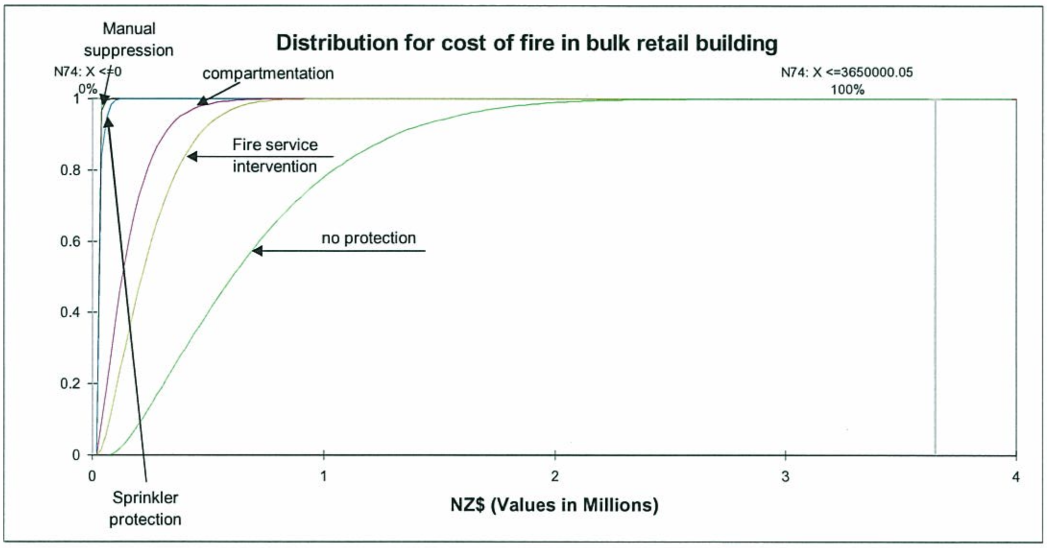
Fire Loss costs	Mean	SD		
Business interruption costs	268	26.8	268.18	$/$m^2$ of fire loss
Direct property costs	1207	120.7	1206.82	$/$m^2$ of fire loss
fire service costs	771	77.1	771.02	$/$m^2$ of fire loss
indirect economic costs	285	28.5	284.94	$/$m^2$ of fire loss
reduced consumption costs	70	7.0	70.40	$/$m^2$ of fire loss
social costs	285	28.5	284.94	$/$m^2$ of fire loss
Total Fire loss costs			2886.31	$/$m^2$ of fire loss

@RISK Correlation Sheet

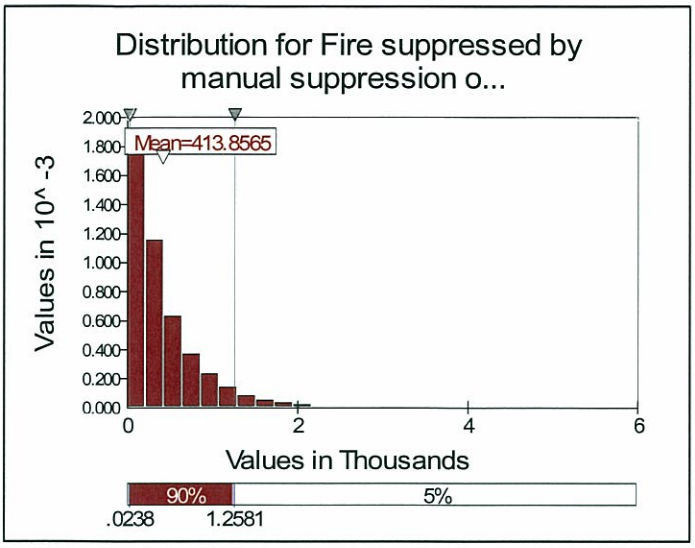
NewMatrix (8x8)	Sheet1!G35 Fire alarm fixed cost	Sheet1!G36 Fire alarm variable cost	Sheet1!G37 Extinguisher cost / unit	Sheet1!G39 Extinguisher maintenance	Sheet1!G41 Sprinkler system installation cost	Sheet1!G44 Fire wall costs	Sheet1!G10 Floor area	Sheet1!G11 Assumed height
Sheet1!G35 Fire alarm fixed cost	1							
Sheet1!G36 Fire alarm variable cost	0	1						
Sheet1!G37 Extinguisher cost / unit	0	0	1					
Sheet1!G39 Extinguisher maintenance	0	0	0	1				
Sheet1!G41 Sprinkler system installation cost	0	0	0	0	1			
Sheet1!G44 Fire wall costs	0	0	0	0	0	1		
Sheet1!G10 Floor area	-0.489543927	0.391635142	0.391635142	-0.391635142	-0.489543927	0	1	
Sheet1!G11 Assumed height	0	0	0	0	0.391635142	0.489543927	0	1

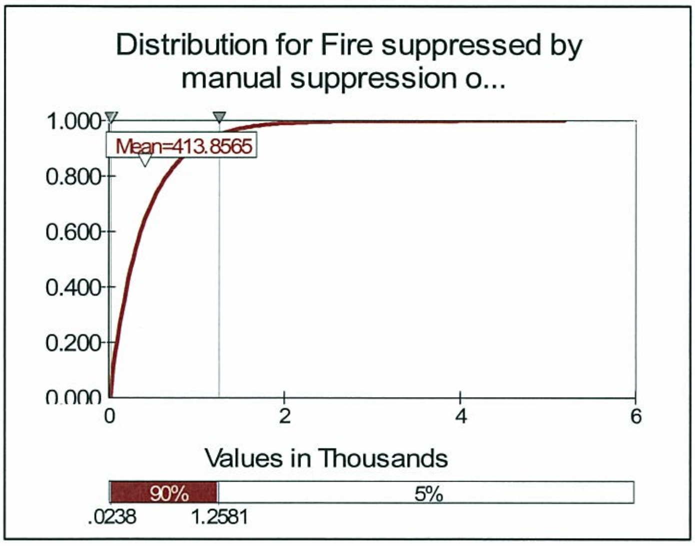
Simulation 4 results table

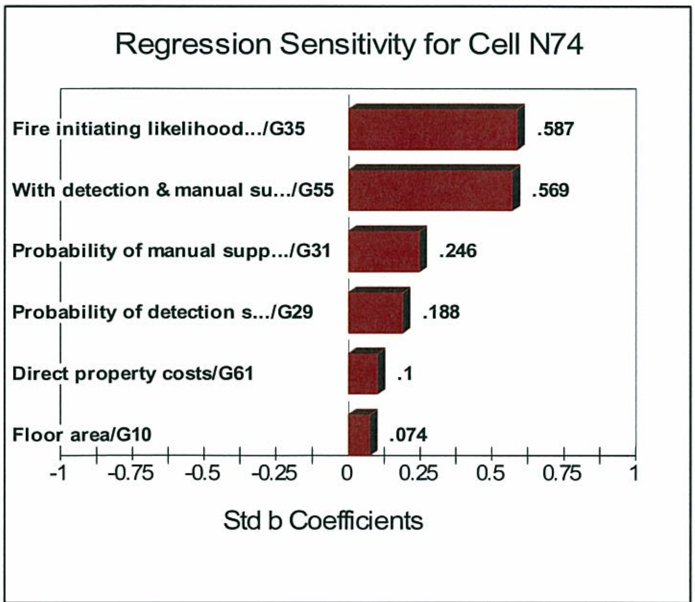
Scenario	Total cost of property loss per fire (NZ$)			other costs (NZ$)	
	Mean	Standard deviation	Upper 95th percentile & rank	Fire Service costs	Indirect Losses
No fire protection (91 - 100% damage)	696677	438519	1556631(7)	691864	442025
Fire service intervention (80% damage)	245230	154359	547934(6)	243536	155593
Manual suppression following manual detection	413	420	1258(1)	412	263
Manual suppression following automatic detection	1704	1675	5128(2)	1698	1085
Sprinkler suppression following failure of manual suppression	13313	11504	35502(3)	13334	8519
Sprinkler suppression no manual suppression applied	23540	18731	61555(4)	23530	15033
Fire contained within single compartment due to sprinkler system failure	157055	112914	378000(5)	155900	99603



Simulation Results for
Fire suppressed by manual suppression on manual detection / Property / N74







Summary Information	
Workbook Name	Simulation 4 Bulk Retail.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	23
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	8/10/2008 4:49
Simulation Stop Time	8/10/2008 4:53
Simulation Duration	00:04:26
Random Seed	1543833332

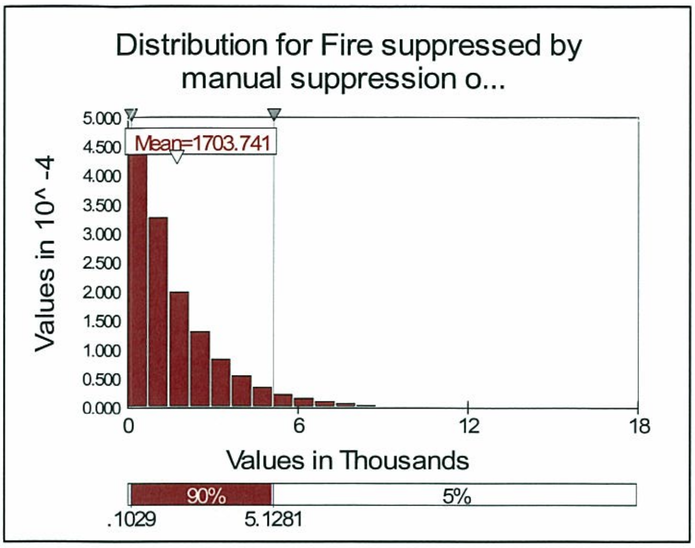
Summary Statistics

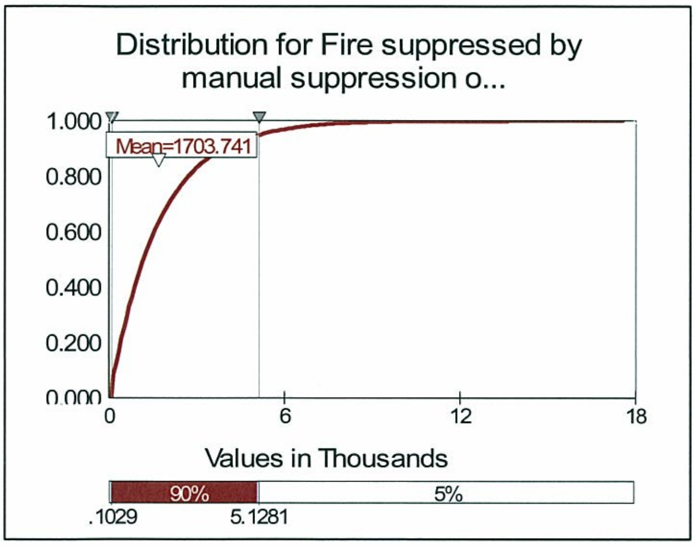
Statistic	Value	%tile	Value
Minimum	0.02	5%	23.84
Maximum	5190.79	10%	47.25
Mean	413.86	15%	71.59
Std Dev	420.69	20%	96.25
Variance	176982.344	25%	122.33
Skewness	2.134219695	30%	149.88
Kurtosis	10.18414078	35%	178.74
Median	280.17	40%	209.56
Mode	40.46	45%	243.00
Left X	23.84	50%	280.17
Left P	5%	55%	320.90
Right X	1258.07	60%	367.06
Right P	95%	65%	422.56
Diff X	1234.23	70%	488.85
Diff P	90%	75%	563.90
#Errors	0	80%	661.37
Filter Min		85%	788.59
Filter Max		90%	955.44
#Filtered	0	95%	1258.07

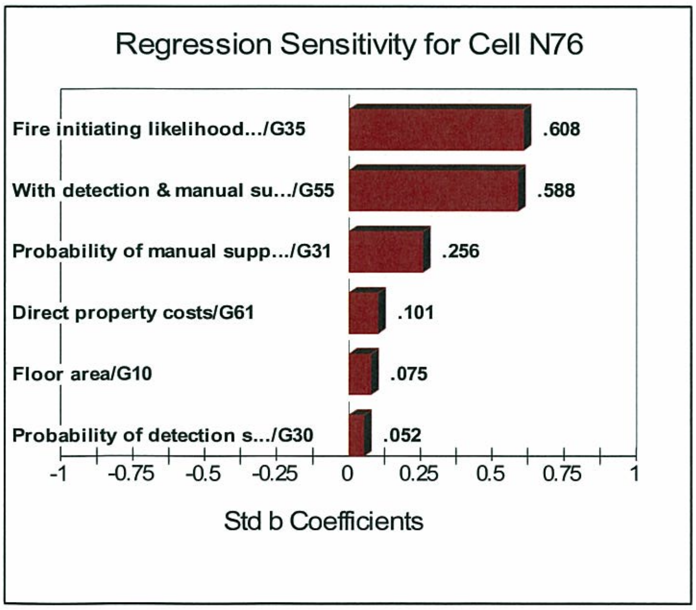
Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.587	0.582
#2	With detection &	0.569	0.691
#3	Probability of ma	0.246	0.236
#4	Probability of det	0.188	0.169
#5	Direct property c	0.100	0.091
#6	Floor area / G	0.074	0.074
#7	Assumed height	0.000	-0.001
#8	Building Cost / $	0.000	0.012
#9	Probability of det	0.000	0.002
#10	Probability of aut	0.000	0.000
#11	Probability of fire	0.000	0.008
#12	Fire alarm fixed c	0.000	-0.033
#13	Fire alarm variab	0.000	0.037
#14	Extinguisher cos	0.000	0.026
#15	Extinguisher mai	0.000	-0.033
#16	Sprinkler system	0.000	-0.034

Simulation Results for
Fire suppressed by manual suppression on automatic detection / Property / N7(







Summary Information	
Workbook Name	Simulation 4 Bulk Retail.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	23
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	8/10/2008 4:49
Simulation Stop Time	8/10/2008 4:53
Simulation Duration	00:04:26
Random Seed	1543833332

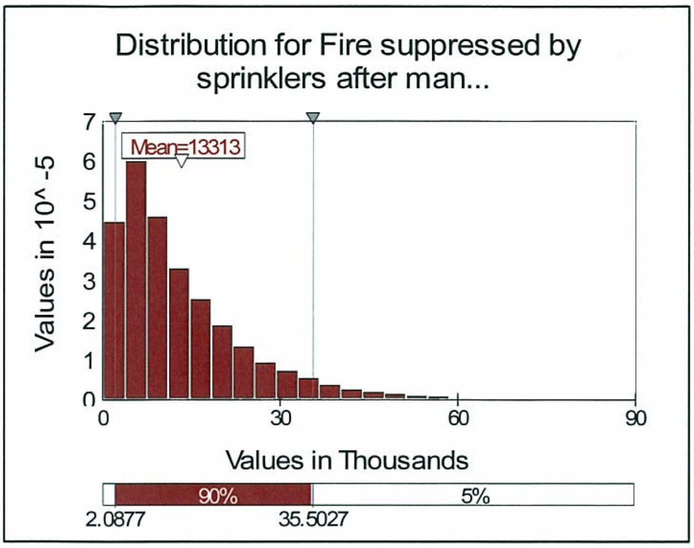
Summary Statistics

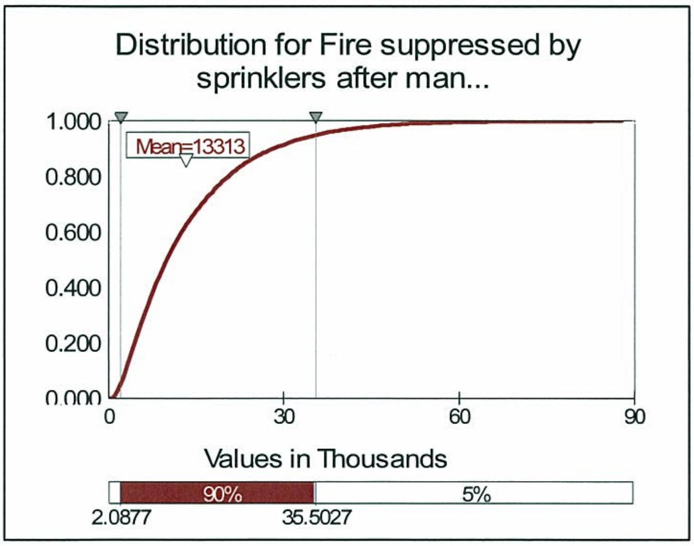
Statistic	Value	%tile	Value
Minimum	0.09	5%	102.88
Maximum	17577.26	10%	202.66
Mean	1703.74	15%	304.28
Std Dev	1674.62	20%	409.90
Variance	2804360.419	25%	518.17
Skewness	1.904946618	30%	634.18
Kurtosis	8.01776093	35%	757.53
Median	1177.95	40%	879.14
Mode	153.72	45%	1022.22
Left X	102.88	50%	1177.95
Left P	5%	55%	1351.41
Right X	5128.10	60%	1541.90
Right P	95%	65%	1771.61
Diff X	5025.23	70%	2032.98
Diff P	90%	75%	2350.28
#Errors	0	80%	2726.19
Filter Min		85%	3205.47
Filter Max		90%	3933.14
#Filtered	0	95%	5128.10

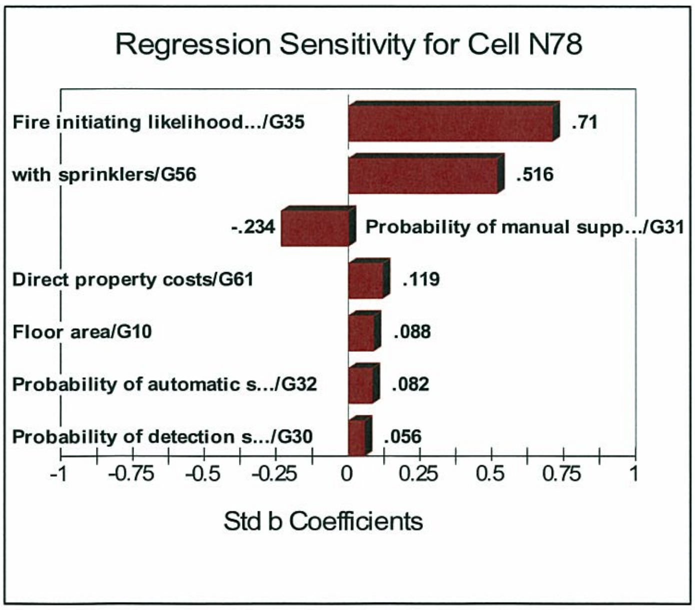
Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.608	0.593
#2	With detection &	0.588	0.701
#3	Probability of ma	0.256	0.240
#4	Direct property c	0.101	0.092
#5	Floor area / G	0.075	0.075
#6	Probability of det	0.052	0.044
#7	Assumed height	0.000	0.000
#8	Building Cost / $	0.000	0.013
#9	Probability of det	0.000	0.001
#10	Probability of aut	0.000	-0.001
#11	Probability of fire	0.000	0.008
#12	Fire alarm fixed c	0.000	-0.033
#13	Fire alarm variab	0.000	0.038
#14	Extinguisher cos	0.000	0.026
#15	Extinguisher mai	0.000	-0.034
#16	Sprinkler system	0.000	-0.033

Simulation Results for
Fire suppressed by sprinklers after manual suppression failed / Property / N78







Summary Information	
Workbook Name	Simulation 4 Bulk Retail.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	23
Number of Outputs	7
Sampling Type	Latin Hypercube
Simulation Start Time	8/10/2008 4:49
Simulation Stop Time	8/10/2008 4:53
Simulation Duration	00:04:26
Random Seed	1543833332

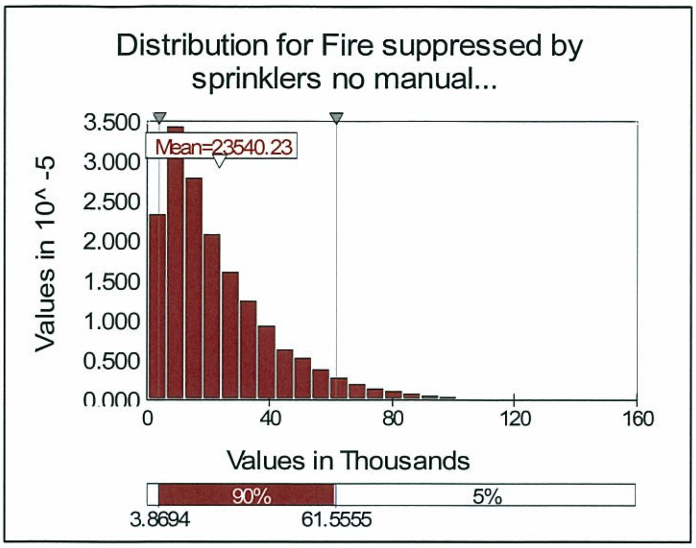
Summary Statistics

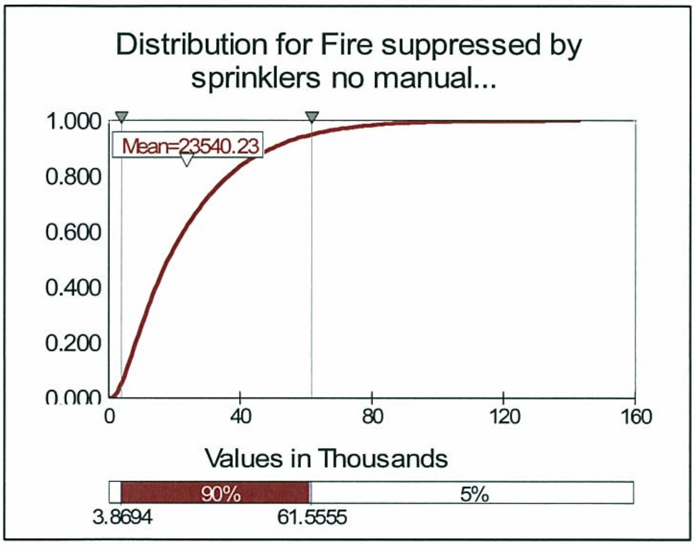
Statistic	Value	%tile	Value
Minimum	293.05	5%	2087.71
Maximum	87874.42	10%	2952.02
Mean	13313.00	15%	3740.52
Std Dev	11054.09	20%	4523.02
Variance	122192939.2	25%	5328.92
Skewness	1.693295989	30%	6139.74
Kurtosis	6.763645512	35%	7032.80
Median	10047.59	40%	7931.20
Mode	3964.92	45%	8958.71
Left X	2087.71	50%	10047.59
Left P	5%	55%	11251.46
Right X	35502.67	60%	12623.17
Right P	95%	65%	14189.28
Diff X	33414.96	70%	15971.68
Diff P	90%	75%	18056.32
#Errors	0	80%	20550.56
Filter Min		85%	23577.25
Filter Max		90%	28202.40
#Filtered	0	95%	35502.67

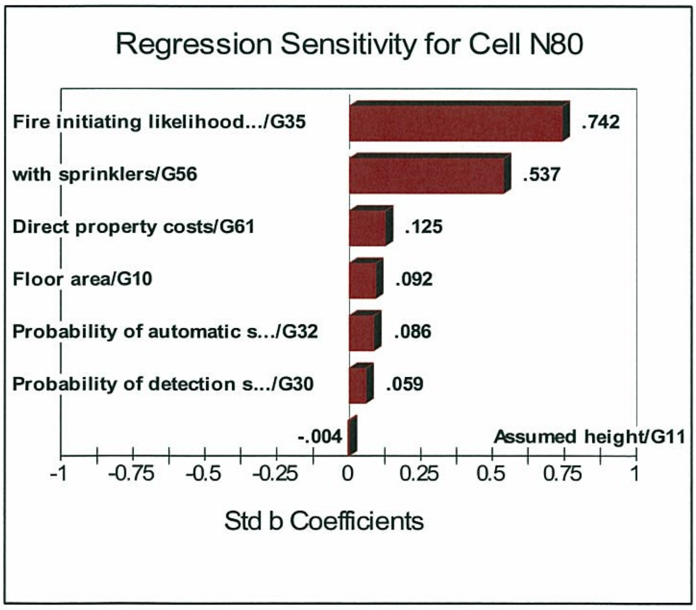
Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.710	0.746
#2	with sprinklers / $	0.516	0.556
#3	Probability of ma	-0.234	-0.214
#4	Direct property c	0.119	0.113
#5	Floor area / G	0.088	0.091
#6	Probability of aut	0.082	0.086
#7	Probability of det	0.056	0.049
#8	Assumed height	0.000	0.002
#9	Building Cost / $	0.000	0.009
#10	Probability of det	0.000	0.007
#11	Probability of fire	0.000	0.002
#12	Fire alarm fixed c	0.000	-0.053
#13	Fire alarm variab	0.000	0.034
#14	Extinguisher cos	0.000	0.023
#15	Extinguisher mai	0.000	-0.035
#16	Sprinkler system	0.000	-0.038

Simulation Results for
Fire suppressed by sprinklers no manual intervention / Property / N80







Summary Information	
Workbook Name	Simulation 4 Bulk Retail.xls
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Simulation Start Time	8/10/2008 4:49
Simulation Stop Time	8/10/2008 4:53
Simulation Duration	00:04:26
Random Seed	1543833332

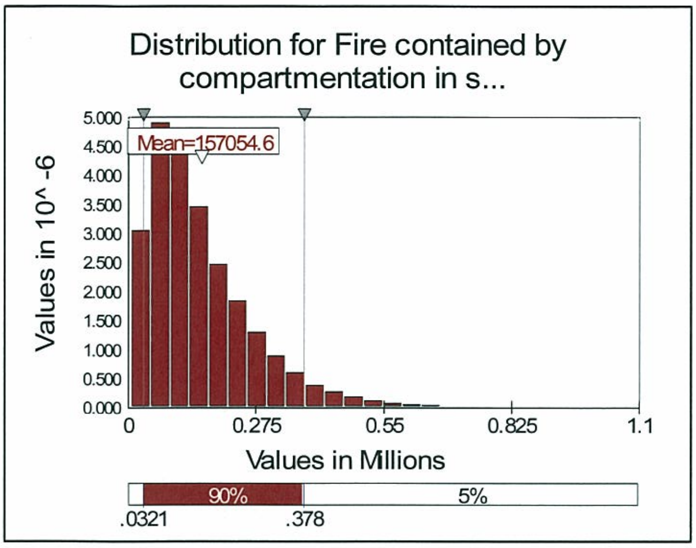
Summary Statistics

Statistic	Value	%tile	Value
Minimum	631.83	5%	3869.43
Maximum	142834.25	10%	5473.72
Mean	23540.23	15%	6904.77
Std Dev	18731.33	20%	8275.49
Variance	350862840.6	25%	9743.68
Skewness	1.522822238	30%	11201.28
Kurtosis	5.797747986	35%	12774.33
Median	18088.17	40%	14373.08
Mode	9278.85	45%	16175.55
Left X	3869.43	50%	18088.17
Left P	5%	55%	20317.81
Right X	61555.53	60%	22729.85
Right P	95%	65%	25468.87
Diff X	57686.10	70%	28513.09
Diff P	90%	75%	32065.24
#Errors	0	80%	36298.38
Filter Min		85%	41624.85
Filter Max		90%	49674.67
#Filtered	0	95%	61555.53

Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.742	0.770
#2	with sprinklers / $	0.537	0.574
#3	Direct property c	0.125	0.116
#4	Floor area / G	0.092	0.093
#5	Probability of aut	0.086	0.086
#6	Probability of det	0.059	0.049
#7	Assumed height	-0.004	0.002
#8	Building Cost / $	0.000	0.009
#9	Probability of det	0.000	0.007
#10	Probability of ma	0.000	0.012
#11	Probability of fire	0.000	-0.001
#12	Fire alarm fixed c	0.000	-0.053
#13	Fire alarm variab	0.000	0.035
#14	Extinguisher cos	0.000	0.025
#15	Extinguisher mai	0.000	-0.035
#16	Sprinkler system	0.000	-0.041

Simulation Results for
Fire contained by compartmentation in single fire cell / Property / N82



Summary Information	
Workbook Name	Simulation 4 Bulk Retail.xls
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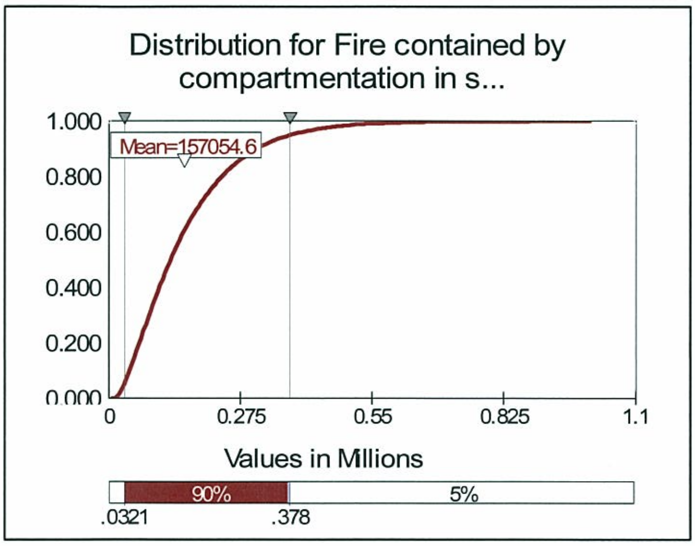
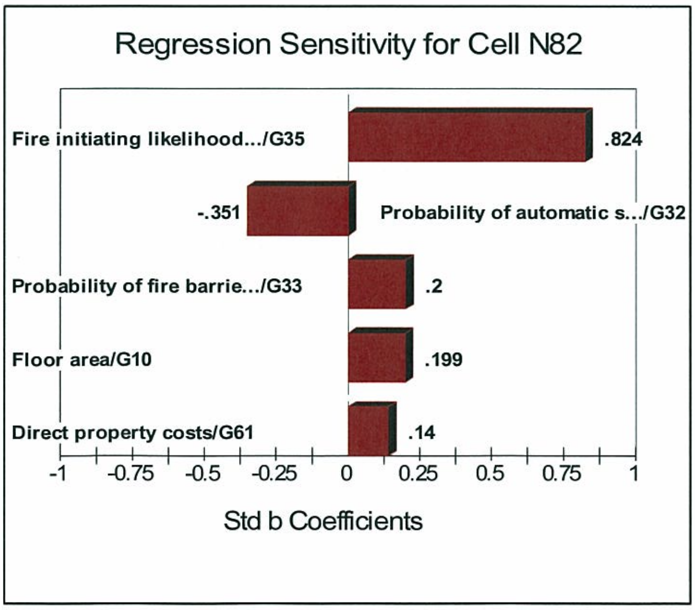
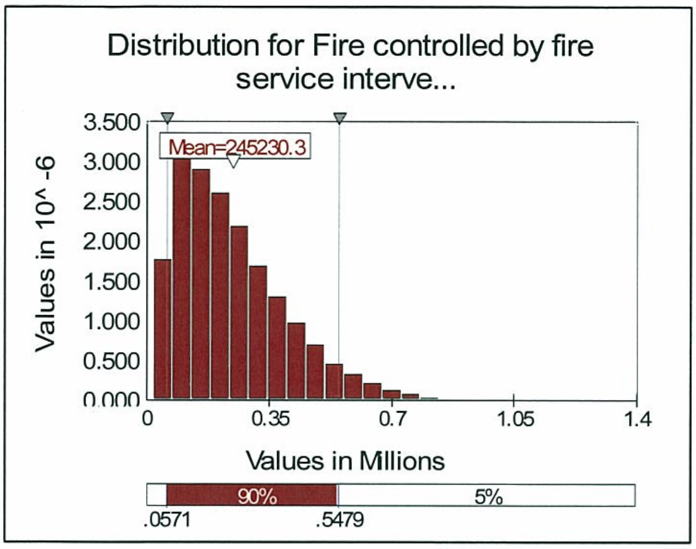


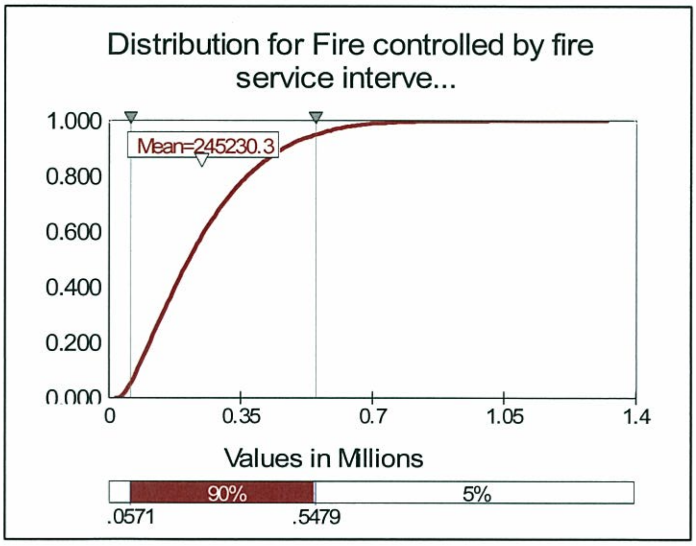
Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	7313.75	5%	32094.52
Maximum	1005999.63	10%	43120.72
Mean	157054.57	15%	53260.79
Std Dev	112914.43	20%	63505.38
Variance	12749668714	25%	73489.04
Skewness	1.491992538	30%	84062.52
Kurtosis	6.086472128	35%	94548.79
Median	128655.71	40%	105389.23
Mode	50378.52	45%	116680.14
Left X	32094.52	50%	128655.71
Left P	5%	55%	141647.13
Right X	377999.66	60%	155445.75
Right P	95%	65%	171545.38
Diff X	345905.13	70%	189990.23
Diff P	90%	75%	211007.41
#Errors	0	80%	235068.75
Filter Min		85%	266730.69
Filter Max		90%	307983.81
#Filtered	0	95%	377999.66

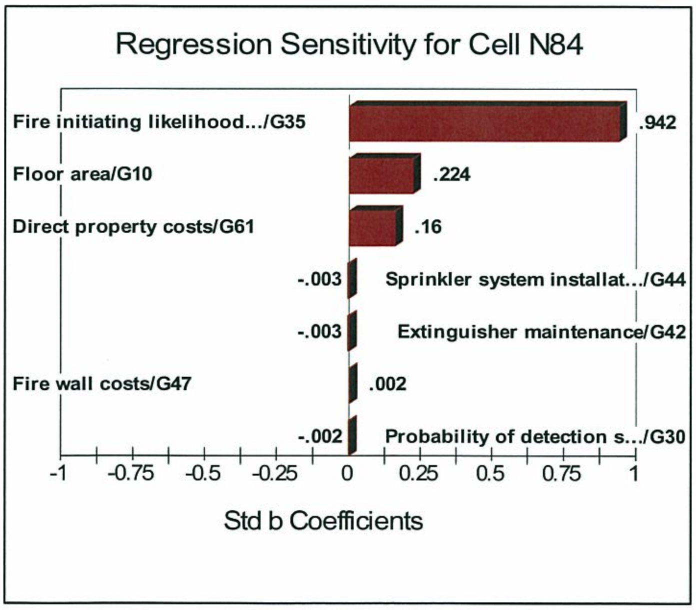


Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Fire initiating like	0.824	0.877
#2	Probability of aut	-0.351	-0.340
#3	Probability of fire	0.200	0.192
#4	Floor area / G	0.199	0.201
#5	Direct property c	0.140	0.134
#6	Assumed height	0.000	-0.008
#7	Building Cost / $	0.000	0.008
#8	Probability of det	0.000	0.000
#9	Probability of det	0.000	-0.004
#10	Probability of ma	0.000	0.008
#11	Fire alarm fixed c	0.000	-0.105
#12	Fire alarm variab	0.000	0.074
#13	Extinguisher cos	0.000	0.071
#14	Extinguisher mai	0.000	-0.077
#15	Sprinkler system	0.000	-0.099
#16	Fire wall costs / $	0.000	-0.006

Simulation Results for
Fire controlled by fire service intervention (80% damage) / Property / N84







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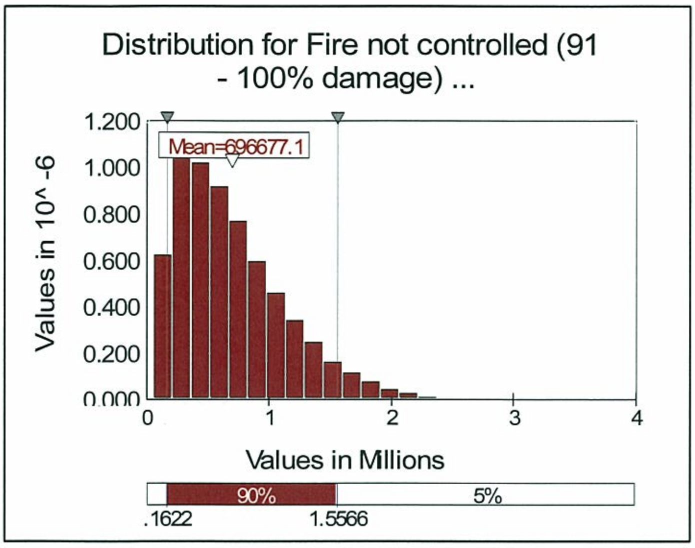
Simulation Duration	00:04:26
Random Seed	1543833332

Summary Statistics			
Statistic	**Value**	**%tile**	**Value**
Minimum	19527.87	5%	57079.96
Maximum	1325281.63	10%	75549.61
Mean	245230.33	15%	92306.77
Std Dev	154358.66	20%	108952.12
Variance	23826595005	25%	125026.63
Skewness	1.03217367	30%	141703.94
Kurtosis	4.028537831	35%	158506.64
Median	213006.28	40%	176200.84
Mode	97231.56	45%	193668.73
Left X	57079.96	50%	213006.28
Left P	5%	55%	232812.11
Right X	547934.31	60%	253699.39
Right P	95%	65%	277195.00
Diff X	490854.35	70%	303165.00
Diff P	90%	75%	332828.81
#Errors	0	80%	366615.97
Filter Min		85%	408368.50
Filter Max		90%	461554.72
#Filtered	0	95%	547934.31

Sensitivity			
Rank	**Name**	**Regr**	**Corr**
#1	Fire initiating like	0.942	0.962
#2	Floor area / G	0.224	0.221
#3	Direct property c	0.160	0.146
#4	Sprinkler system	-0.003	-0.106
#5	Extinguisher mai	-0.003	-0.085
#6	Fire wall costs / $	0.002	-0.003
#7	Probability of det	-0.002	-0.004
#8	Assumed height	0.000	-0.002
#9	Building Cost / $	0.000	0.011
#10	Probability of det	0.000	0.002
#11	Probability of ma	0.000	0.007
#12	Probability of aut	0.000	-0.004
#13	Probability of fire	0.000	0.003
#14	Fire alarm fixed c	0.000	-0.112
#15	Fire alarm variab	0.000	0.084
#16	Extinguisher cos	0.000	0.076

Simulation Results for
Fire not controlled (91 - 100% damage) / Property / N86



Summary Information	
Workbook Name	Simulation 4 Bulk Retail.xls
Number of Simulations	1
Number of Iterations	25000
Number of Inputs	23
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Sampling Type	Latin Hypercube
Simulation Start Time	8/10/2008 4:49
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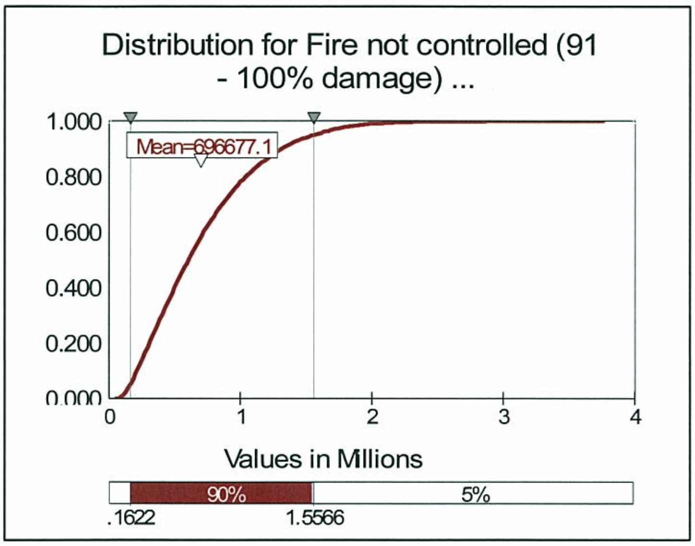
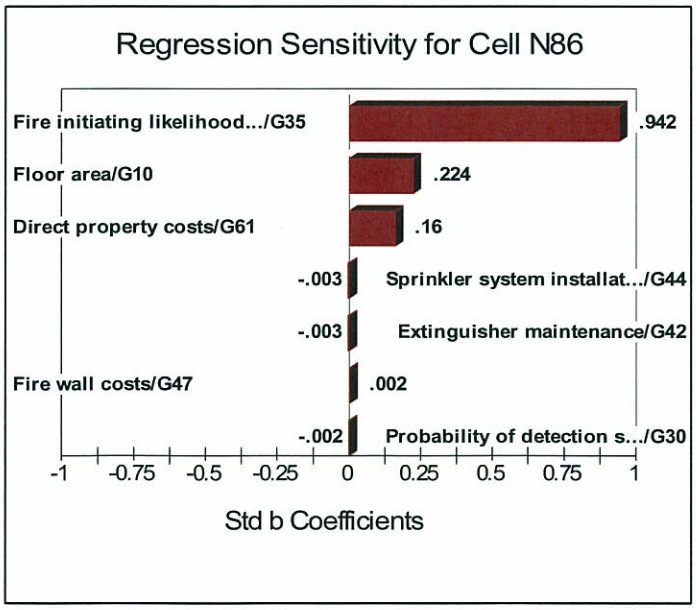
Simulation Duration	00:04:26
Random Seed	1543833332



Summary Statistics

Statistic	Value	%tile	Value
Minimum	55476.89	5%	162158.98
Maximum	3765004.50	10%	214629.58
Mean	696677.08	15%	262235.16
Std Dev	438518.91	20%	309523.06
Variance	1.92299E+11	25%	355189.28
Skewness	1.032173666	30%	402568.00
Kurtosis	4.028537803	35%	450302.97
Median	605131.50	40%	500570.59
Mode	276226.02	45%	550195.25
Left X	162158.98	50%	605131.50
Left P	5%	55%	661398.06
Right X	1556631.63	60%	720736.88
Right P	95%	65%	787485.81
Diff X	1394472.64	70%	861264.19
Diff P	90%	75%	945536.38
#Errors	0	80%	1041522.63
Filter Min		85%	1160137.75
Filter Max		90%	1311235.00
#Filtered	0	95%	1556631.63



Sensitivity

Rank	Name	Regr	Corr
#1	Fire initiating like	0.942	0.962
#2	Floor area / G	0.224	0.221
#3	Direct property c	0.160	0.146
#4	Sprinkler system	-0.003	-0.106
#5	Extinguisher mai	-0.003	-0.085
#6	Fire wall costs / $	0.002	-0.003
#7	Probability of det	-0.002	-0.004
#8	Assumed height	0.000	-0.002
#9	Building Cost / $	0.000	0.011
#10	Probability of det	0.000	0.002
#11	Probability of ma	0.000	0.007
#12	Probability of aut	0.000	-0.004
#13	Probability of fire	0.000	0.003
#14	Fire alarm fixed c	0.000	-0.112
#15	Fire alarm variab	0.000	0.084
#16	Extinguisher cos	0.000	0.076